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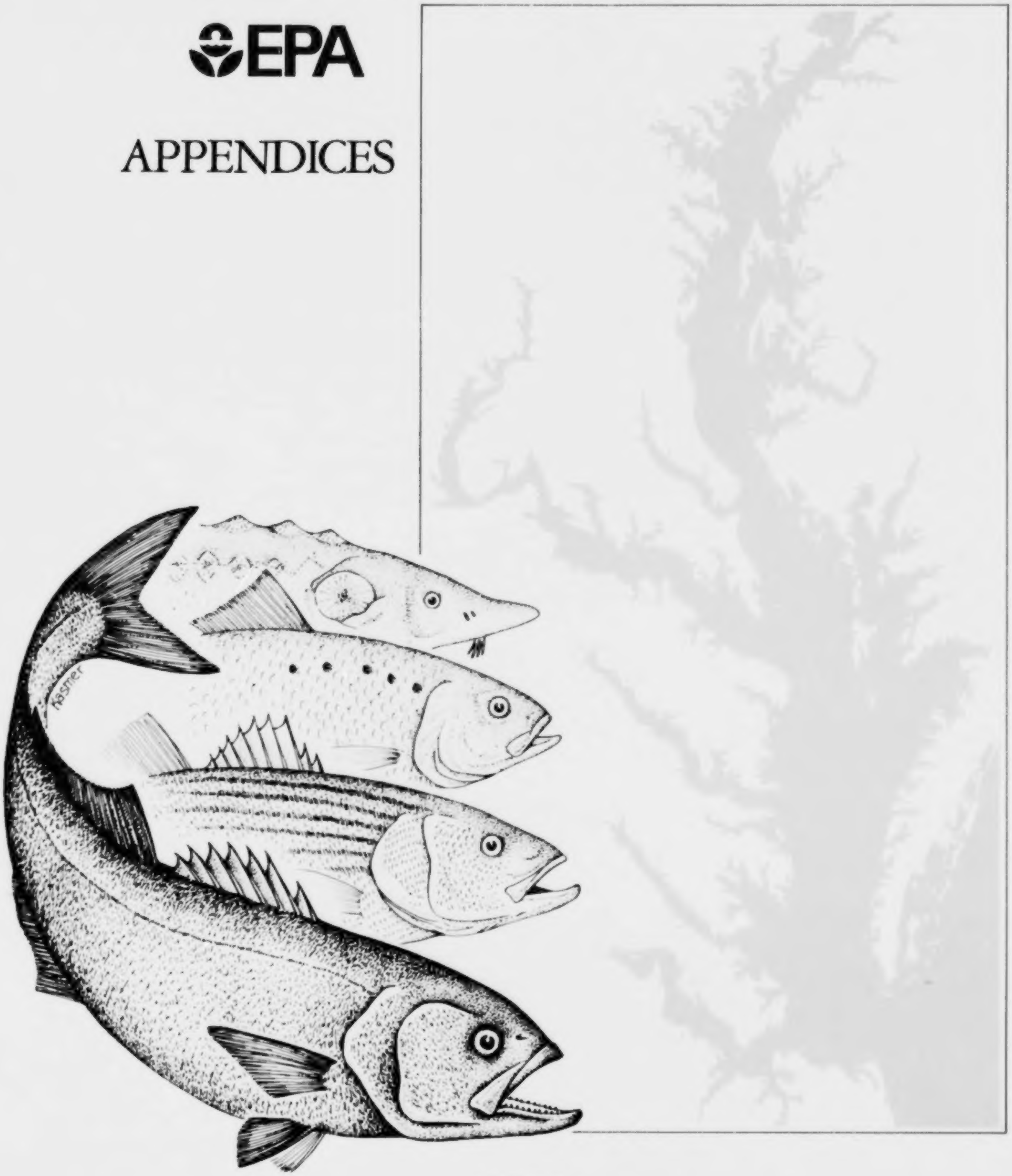

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CHESAPEAKE BAY PROGRAM: A PROFILE OF ENVIRONMENTAL CHANGE

APPENDICES

September 1983

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PREFACE

This document includes the four appendices to the report Chesapeake Bay: A Profile of Environmental Change developed by the Environmental Protection Agency's Chesapeake Bay Program. The report and its appendices provide a characterization of the Bay's water quality and resources.

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SECTION 1

THE CHESAPEAKE BAY ENVIRONMENT

Many physical, chemical, and biological components make up the Bay environment and are connected in sometimes complex processes and relationships. To accurately interpret the quality of the Bay's waters and sediments, and the health of its major resources, several physical elements and some important biological interactions had to be considered.

These processes are numerous and will not be discussed in this volume. To better understand these interactions, we suggest that the reader consult any of the following publications:

Chesapeake Bay: Introduction to an Ecosystem (U.S. EPA 1982a);
Chesapeake Bay Program Technical Studies: A Synthesis (U.S. EPA 1982b);
"The Biology of an Estuary" (Cronin et al. 1971);
"A Conceptual Ecological Model for Chesapeake Bay" (Green 1978);
Estuaries (Lauff 1967)
The Chesapeake Bay in Maryland - An Atlas of Natural Resources (Lippson 1973);
"Estuarine Circulation Patterns" (Pritchard 1955);
Chesapeake Bay Future Conditions Report (U.S. Army Corps of Engineers 1977); and
Beautiful Swimmers (Warner 1976).

SECTION 2
SEGMENTATION CONCEPT

(adapted from Klein, unpublished)

The Bay is a fluid system with few obvious boundaries save perhaps the sea surface and the water-sediment interface. Scientists, managers, and users of the Bay are more likely to see smooth variations from place to place, rather than a system composed of separable parts. The person who would partition the Bay to aid in management is, therefore, faced with a dilemma -- on the one hand, fixed simple boundaries seem too rigid in a fluid system, and, on the other hand, time variable boundaries based on intricate schemes violate the criterion of simplicity.

Because of this dilemma, the Chesapeake Bay Program (CBP) planned to divide the Bay into regions, or segments, to assess and map past and present conditions. Segmentation can be used as an analytical tool that recognizes the Bay as an interrelated ecosystem, composed of physically, chemically, and biologically diverse areas.

Using segmentation to look at water quality is not new. Planning agencies for the Great Lakes divided the lakes into zones with similar nutrient and chlorophyll a levels to monitor eutrophication. To locate acceptable sites for dumping treated sewage, planners segmented San Francisco Bay into six major areas according to flushing characteristics. Under the Clean Water Act of 1977, all streams in the United States are segmented according to the water quality and assimilative capacities of the stream (40 CFR131, U.S. Code of Federal Regulations Section 131).

Ideally, the segmentation approach would segment the Bay into areas demonstrating like physical, chemical, and biological characteristics. However, realizing that biotic communities result from abiotic regulators such as nutrients and salinity, we simplified the approach by using physical processes to segment the Bay into like classes. To segment Chesapeake Bay, we used circulation, salinity, and geomorphology.

BIOLOGICAL AND CHEMICAL CHARACTERIZATION OF SEGMENT BOUNDARIES

Main Bay

The first segmentation boundary is between CB-1 and CB-2 and separates Susquehanna Flats from the upper Bay and lies in the region of maximum penetration of sea salt at the head of the Bay (Figure 1). Most freshwater plankton are not expected to grow and flourish south of this region, although some plankton may be continually brought into the area by the Susquehanna River.

The second boundary between CB-2 and CB-3 demarcates the southern limit of the turbidity maximum, a region where suspended sediment causes light limitation of phytoplankton production most of the year. This boundary also coincides with the long-term summer average for the 5 ppt salinity contour -- an important physiological parameter for oysters.

The third boundary at the Bay Bridge, between CB-3 and CB-4, marks the northern limit of deep water anoxia in Chesapeake Bay and the 10 ppt salinity contour. In segment CB-4, water deeper than about 10 meters[1]

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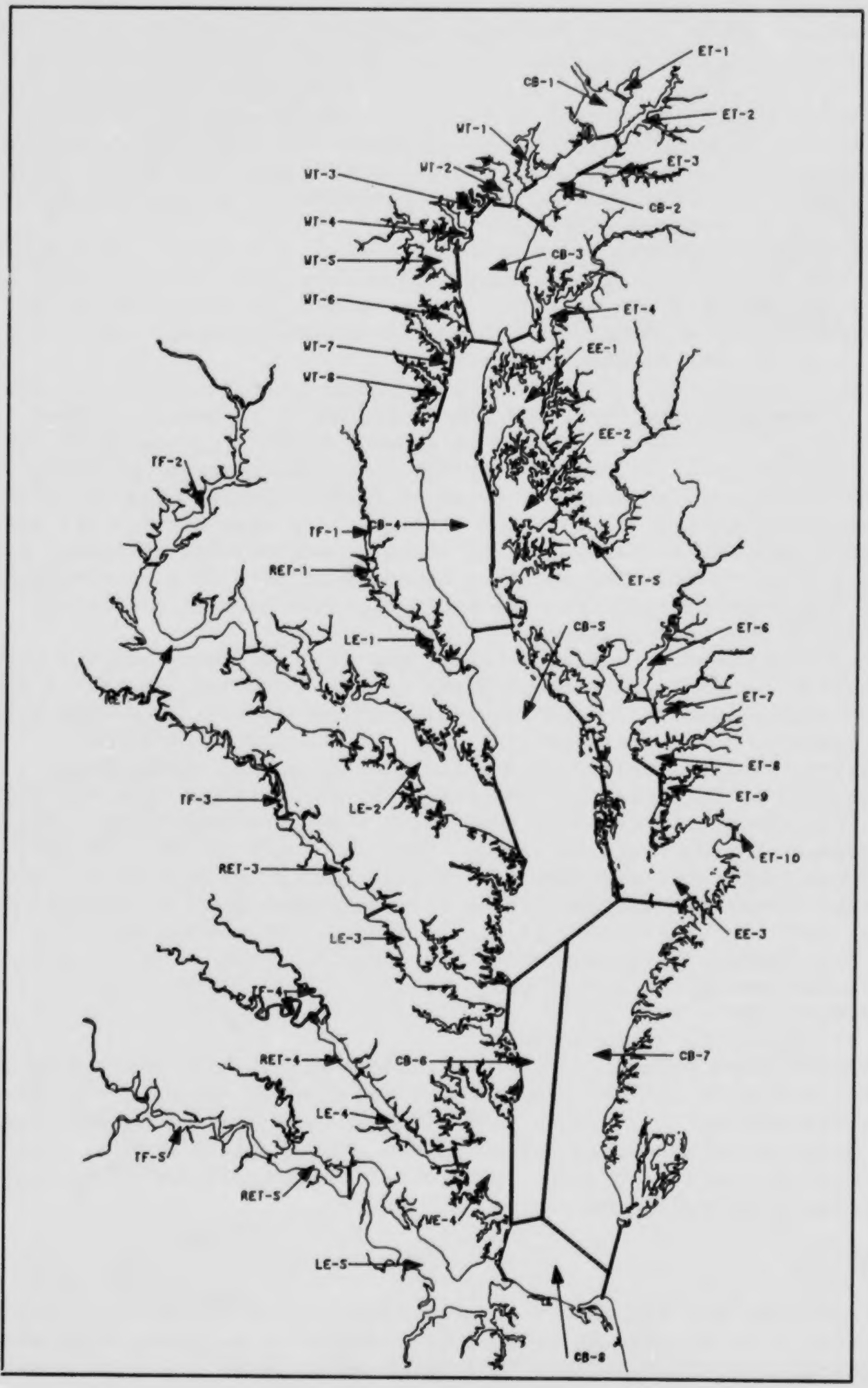
[1] 1 meter = 3.28 feet


ET-1
CB-1
ET-2
WT-1
ET-3
WT-2
WT-3
CB-2
WT-4
CB-3
WT-5
WT-6
ET-4
WT-7
EE-1
WT-8
EE-2
TF-2
TF-1
CB-4
RET-1
ET-5
CB-5
ET-6
LE-1
RET-2
ET-7
ET-8
TF-3
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ET-9
ET-10
RET-3
EE-3
LE-3
TF-4
RET-4
CB-6
CB-7
LE-4
TF-5
RET-5
WE-4
LE-5
CB-8

Figure 1. Chesapeake Bay Program segments used in data analysis.

usually experiences oxygen depletion in summer that may result in anoxia and hydrogen sulfide production. When anoxia occurs, these deep waters are toxic to fish, crabs, shellfish, and other demersal and benthic animals. The anoxic layer is also rich in nutrients that may reach the surface layer by diffusion, mixing, and vertical advection. In the spring, the region near the bridge is the site where phytoplankton and fish larvae traveling in the deep layer from the Bay mouth are brought to the surface by a combination of physical processes.

The fourth boundary, between CB-4 and CB-5, a transect located at Cove Point, was established at a narrows; below this point, the Patuxent and Potomac Rivers enter the main Bay. This segment is characterized by salinities of 12 to 13 ppt in the long-term summer average and lies mid-way in the area subject to summer anoxia.

The fifth boundary, between CB-5 and CB-6-7, approximates the southern limit of summer anoxic water and the 18 ppt salinity contour. Most of the deeper areas of the Bay are found in segment CB-5. Segment CB-5, like CB-4, experiences considerable nutrient enrichment during the summer when both phosphate and ammonium are released from suspended organic material and bottom sediments. This region also exhibits high nitrite and nitrate concentrations in the fall when the ammonium accumulated in summer is oxidized by bacteria. The southern boundary of CB-5 also approximates the region where the nitrate from the spring freshet becomes a critical nutrient for the phytoplankton.

The fifth boundary separates the lower Bay into three regions with different circulation patterns. North of this boundary, the Bay's density stratification results in two distinct vertical layers. The deep water there moves in a net upstream flow, and the surface layer flows downstream. Between this boundary and the Bay mouth, the density distribution tends toward a cross-stream gradient rather than vertical one. This results in net advective flows throughout the water column, on the average to flow north in segment CB-7 and south in CB-6 and CB-8. This pronounced horizontal gradient also exists across the Bay mouth. Thus, planktonic organisms and the larvae of catadromous fish are brought into the Bay with the higher salinity ocean water along the eastern side of the lower Bay, until they become entrained into the lower layer at segment CB-5 and are carried up the Bay to grow and mature. Also, the high rates of sand deposition in this segment are thought to be imported from the inner shelf region at the ocean boundary.

Eastern Shore embayments such as Eastern Bay (EE-1), the sub-estuary of the Choptank River (EE-2), and Pocomoke and Tangier Sounds (EE-3) have salinities similar to adjacent Bay waters and are shallow enough to permit light penetration necessary for submerged aquatic plant growth. These areas provide shelter for many invertebrates and small fish that contribute to the Bay's natural richness.

Tributaries

Boundaries have been shown across the mouths of the Bay's tributaries. They serve to delineate the sources of freshwater, sediment, nutrients, and phytoplankton seed populations that may grow to bloom concentrations in the main Bay. Also along these boundaries, frontal zones between tributary and main Bay water tend to concentrate detrital matter and nutrients, making them important mechanisms in the food chain of organisms depending upon circulation to bring them in contact with their food source.

The major tributaries are also further divided into three segment types: tidal fresh (TF), river-estuarine-transition zone (RET), and lower sub-estuary (LE). The tidal-fresh segments are biologically important as spawning areas for anadromous and semi-anadromous fish such as the alewife, herring, shad, striped bass, white perch, and yellow perch. There are also freshwater species that are resident to these areas such as catfish, minnows, and carp. Also frequently encountered during the summer-time in the tidal-fresh areas is the possible occurrence of blue-green algae blooms. The extent of these blooms is dependent upon nutrient supply, retention time, and availability of light; however, these populations are inhibited as they encounter the more saline waters associated with the transition zone.

The greatest concentration of suspended material occurs at the interface of fresh and saline waters, and it approximates the terminus of density dependent estuarine circulation. This phenomenon is typically referred to as the maximum turbidity. The significance of this area lies in its value as a sediment trap, entraining not only material introduced upstream but, additionally, material transported in the lower layer from downstream. This mechanism also tends to concentrate any material associated with the entrained sediment, as evidence by the Kepone incident within the James River. Kepone concentrations within the river were highest in the zone of maximum turbidity.

The final segment type found within the major tributaries is identified as the lower sub-estuary segment. This area extends from the turbidity maximum to the point where the tributary enters the main Bay. Within these areas exist highly productive oyster bars. Oyster distribution, based upon the Baylor bottom survey, shows heavy concentration of bars in the lower sub-estuaries because of the favorable depth, salinities, and substrate. In general, bars are located in depths of less than 11.5 m in salinities greater than 7 to 8 ppt and on substrates that are firm. Seasonal deficiencies in dissolved oxygen (DO) prevent their establishment in most waters over 11.5 m deep; as a consequence, they are not found within the channel areas of these segments.

CONCLUSIONS

The segmentation scheme as proposed, using physical processes, does in general track with the major chemical and biological processes. This will be continually refined as data becomes available, allowing for extrapolation of cause and effect relationships among segments of similar physical characteristics.

The refinement as suggested above will enable sub-segmenting based upon more segment-intensive data such as sedimentary structure because many benthic communities can only tolerate specific kinds of bottom materials. A second refining criterion is depth. Water column data will be sub-segmented by depth into upper and lower layer. The 10 meter depth profile will distinguish between upper and lower layer sub-segments since it is typically associated with the boundary between outward flowing upper layer and landward flowing lower layer.

The main quality being strived for in this segmentation approach is flexibility. Depending upon the problem being addressed, segments can be collapsed to look at; for instance, an entire tributary or can be refined or sub-segmented to address a certain near-field problem associated with a particular power plant or sewage treatment plant outfall. These diverse areas, once identified and understood, can be managed to maintain or enhance their uses.

PRINCIPAL SEGMENT CHARACTERISTICS

Some principal characteristics selected for each of the segments are shown in Table 1.

Estuaries have a capacity to assimilate waste before experiencing significant ecological damage; this ability can vary dramatically from one area to another. To assess the water quality of areas with similar characteristics, the CBP divided the Bay into regions, or segments, using natural processes such as circulation and salinity. These 45 segments were used as a framework to map and evaluate past and present conditions of Chesapeake Bay.

TABLE 1. SEGMENTS OF CHESAPEAKE BAY AND THEIR PRINCIPAL SEGMENT CHARACTERISTICS

Segment	Characteristics
Tidal-fresh reaches	
Ches. Bay N. (CB-1) Up. Patuxent (TF-1) Up. Potomac (TF-2) Up. Rapp. (TF-3) Up. York (TF-4) Up. James (TF-5)	o dominated by freshwater inflow of the river system o spawning areas for anadromous and semi-anadromous fish o resident habitat for freshwater fish o dominated by freshwater plankton and aquatic vegetation
Transition zones	
Up. Bay (CB-2) M. Patuxent (RET-1) M. Potomac (RET-2) M. Rapp. (RET-3) M. York (RET-4) M. James (RET-5)	o slight salinity (3 to 9 ppt, mean) influence o zones of maximum turbidity where suspended sediment causes light limitation of phytoplankton production most of the year o areas are valuable sediment traps, concentrating material associated with sediments including adsorbed toxic chemicals
Lower estuarine reaches	
Up. C. Bay (CB-3) L. Patuxent (LE-1) L. Potomac (LE-2) L. Rapp. (LE-3) L. York (LE-4)	o upstream limit of deep water anoxia o moderate salinity (7 to 13 ppt, mean) o two-layer, estuarine circulation driven primarily by freshwater inflow
L. James (LE-5) Sec. W. Trib. (WT-1-8) E. S. Trib. (ET-1-10)	o weaker estuarine circulation characterized by limited flow/flushing characteristics o water quality controlled by the density structure of the main stem of the Bay at the tributary mouth
Lower Main Bay	
Chesapeake Bay Lower Central (CB-4)	o water deeper than 9.2 m usually experiences oxygen depletion in summer -- can be toxic to fish, crabs, shellfish, and benthic animals o mean salinity of 9 to 14 ppt o rich in nutrients
Chesapeake Bay South (CB-5)	o influenced by inflow from Potomac and Patuxent and rich in nutrients o mean salinity of 10 to 17 ppt o subject to summer anoxia and contains most of the deeper Bay waters
Chesapeake Bay General West (CB-6)	o net southward flow o mean salinity of 14 to 21 ppt

(continued)

TABLE 1. (Continued)

Segment	Characteristics
Chesapeake Bay General East (CB-7)	o net northward flow o mean salinity of 19 to 24 ppt
Chesapeake Bay Mouth (CB-8)	o net southeastward flow o mean salinity of 19 to 23 ppt.
Embayments	
E. Bay (EE-1) L. Choptank (EE-2) Tangier Sound (EE-3) Mobjack Bay (WE-4)	o have salinities similar to adjacent Bay waters o shallow enough to permit light penetration for submerged aquatic vegetation growth o influenced strongly by wind patterns

SECTION 3

OBTAINING THE CHARACTERIZATION DATA SET

After the CBP defined the segments of the Bay, we were able to characterize them by determining water quality and resource conditions for each one. To collect the appropriate physical and chemical data bases to use in characterization, a data information request was distributed to CBP staff and key investigators. The spatial and temporal resolution, and analytical method were described for each variable. These characterization sheets of physical and chemical data were then compiled and analyzed for the nature and comparability of the field data. To facilitate analysis, the information was entered into a computer and displayed in a variety of ways. For example, the sources of data and variables sampled were displayed by segment in a table format and in histograms of sampling frequency for specific variables across all segments. To supplement this information, appropriate additional data bases were obtained to create the CBP comprehensive water and sediment quality data base. The data base continues to be updated and will be available to Bay researchers and managers. Table 2 summarizes the major data bases.

Nutrient data collected by the researchers funded through the Bay Program were combined with recent and historical data acquired from several other agencies and institutes. These data were subjected to intense quality assurance (QA) procedures to ensure that each represented the collected information and, furthermore, to ensure compatability with regard to units of measurement so that the various data sets could be analyzed as one. The QA procedures applied to the data were a combination of graphical, statistical, and common-sense procedures. The data were first plotted using a representative symbol for each source to identify measurement unit errors as well as obvious key punch and formatting problems. Following the correction of the problems identified in this first step, seasonal and annual means were plotted, again preserving the source identity, to determine any compatibility problems that were not identified earlier. Next, the data were used to calculate means and standard deviations. Potential outliers, or points that are statistically unexpected, were then identified. These potential outliers were examined, and researchers checked the source information as far back as possible for clarification and accuracy. Those outlier points that could not be explained were flagged for elimination in the analytical effort, but the values still remain in the data base. A final check examined the data against limits established by the scientific researchers. These limits were based upon the location of the data within the Bay as well as type of data (e.g., water column or bed sediment). Once all the attempts to justify these potential outliers were exhausted, those points exceeding limits were flagged and eliminated from further analyses. A summary of data sets is shown in Table 3.

Because it was not possible to look at or use all the variables in all the data sets, the Chesapeake Bay Program selected a subset of physical and chemical variables for extensive analysis based on their role in the Bay ecosystem (Table 4).

PHYSICAL AND CHEMICAL VARIABLES

The distribution and stability of Bay environments depends on three very important physical characteristics of the water -- temperature, salinity, and turbidity. Temperature dramatically affects the rates of chemical and biochemical reaction within the water. Salinity, the concentration of dissolved salts in the water, also has an effect on the distribution and well-being of the various biological populations living in the Bay. Turbidity significantly affects plant life; too much suspended

TABLE 2. WATER AND SEDIMENT QUALITY DATA BASES

Physical Variables/Nutrients

Agency	Temporal Coverage	Data Base Description	Parameters
Chesapeake Bay Institute	1949-1980	Bay, river, nutrient, AESOP, Special, Model, Whaley-Carpenter, Pro-Con	Temperature, salinity D.O., pH, Chl-a, nutrients
Virginia Institute of Marine Science	1970-1980	Slackwater	Temp., sal., D.O., BOD, Secchi, Chl-a, nutrients
Maryland Office of Environmental Programs	1966-1972	STORET/MD 106	Temp., sal., D.O.
	1973-1980		Temp., D.O., BOD, pH, Chl-a, nutrients
Virginia State Water Control Board	1964, 1967-1980	STORET/VA 106	Temp., D.O., BOD, pH, turbidity, nutrients
Virginia Bureau of Shellfish Sanitation	1964-1982	STORET	Fecal coliforms
Maryland Department of Health	1968-1980	Maryland Shellfish Sampling Stations	Fecal coliforms
EPA, Annapolis Central Regional Lab	1965-1979	Main Bay	Temp., conductivity, D.O., BOD, Secchi, Chl-a, nutrients
	1965-1970	Potomac	
EPA, Chesapeake Bay Program	1980	CRIMP - Taft	Temp. Sal., D.O., flow, nutrients, Chl-a
	1977-1980	USGS, Fall Line	

(continued)

TABLE 2. (continued)

Agency	Temporal Coverage	Data Base Description	Parameters
Toxic Substances			
Maryland Office of Environmental Programs	1970-1981	Haire - sediment	Heavy metals
	1971-1981	Eisenberg - tissue	Heavy metals, PCB's, pesticides
Virginia State Water Control Board	1970-1981	Gilinsky - sediment and tissue, VA-106	Heavy metals, organic compounds
U.S. Environmental Protection Agency	1962-1981	STORET water, tissue, sediment	Heavy metals, pesticides, organics
Chesapeake Bay Program	1977-1981	Helz - sediment Nichols - sediment/water National Bureau of Standards-sediment/water	Heavy metals
		U.S.G.S., sediment/water	Heavy metals,
		Monsanto, sediment/water	Organics
		Huggett, sedment/tissue	Organics

TABLE 3. SUMMARY OF DATA TESTS AND STATISTICAL ANALYSES (WATER AND SEDIMENT QUALITY DATA BASE)

Data Tests

1. Maps of station locations. (Stations were keyed to appropriate CBP segment, locations corrected if inaccurate, inappropriate stations deleted.)

2. Spatial/temporal plots of observed data, means, minimums, and maximums noted. (Outliers were identified and if unrealistic were eliminated.)

3. Comparison of means of data bases to determine bias in data base. (Problems with data base conversions or comparability of analytical techniques were noted and corrected.)

4. Determination of duplication. (Duplicate observations due to data base mergers were identified and deleted.)

Statistical Analyses

1. Univariate statistics computed for corrected data base by segment and appropriate temporal scale. Maps of "average" condition developed.

2. Linear regressions over varying time windows to determine historical trends. Maps indicating trends over time developed.

3. Log transformation of data, and non-parametric tests were conducted when appropriate to more clearly discern trends.

4. Statistical correlations between variables utilized for interpretation (i.e., sediment size versus metal concentrations; salinity versus nutrient concentrations).

TABLE 4. WATER AND SEDIMENT QUALITY VARIABLES

Physical/Chemical	Nutrient	Toxic	Biological
freshwater flow	total phosphate	total polynuclear aromatics (PNAs)	chlorophyll *a*
temperature	orthophosphate PO_4	dieldrin	coliforms
wind	total nitrogen	terpenoid*	
salinity	inorganic nitrogen	DDT	
dissolved oxygen	nitrate (NO_3)	copper (Cu)	
pH	nitrite (NO_2)	zinc (Zn)	
sediment size	ammonium (NH_4)	cobalt (Co)	
turbidity (secchi disk)	organic nitrogen	nickel (Ni)	
		chromium (Cr)	
		lead (Pb)	
		cadmium (Cd)	
		mercury (Hg)	

*An unsaturated hydrocarbon occurring in most essential oils and oleoresins of plants.

material in the water can prevent essential light from reaching submerged vegetation in the Bay, thus halting growth. Very turbid water can also impair the feeding of organisms relying on sight, and prevent the setting of oyster spat.

Chemical variables such as DO, pH, nutrients, metals, and organic chemicals are important considerations to characterization for they influence productivity in the Bay and are useful overall water quality indicators. Dissolved oxygen is affected by temperature, salinity, circulation, photosynthesis, respiration, and oxygen demand. Low DO radically affects the distribution of living organisms. In water of low salinity, unfavorable pH levels (those below 5) can affect the spawning habitats of anadromous fish and other organisms.

Nutrients, primarily nitrogen and phosphorus, play a critical role in the Bay's ecosystem; they are the structural raw materials for the plant life that in turn, forms the base of the food chain. Inorganic forms, such as phosphate (PO_4), nitrate (NO_3), nitrite (NO_2), and ammonium (NH_4) are cycled through the ecosystem via chemical and biological processes. Increasing urbanization and agricultural use of the Bay watershed, with the accompanying input of nutrients from land runoff, municipal sewage, and industrial effluent discharges can increase nutrient levels above natural levels in certain parts of the Bay. The result is often excessive algal growth. Excessive algal blooms can cause low oxygen conditions due to night respiration of the plants or decay of the organic plant material.

Although certain metals are necessary for some organisms to live, some metals (inorganic chemicals) and organic chemicals are lethal to aquatic organisms in particular quantities. Lower levels of contamination can result in accumulation of toxic materials in tissues of fish and shellfish. Toxic materials can thus be transferred up the food chain, even to man, as evidenced by the mercury contamination of Minamata Bay, Japan. Chronic effects can also impair reproduction, change swimming patterns and growth.

An assessment of fecal coliform levels was included in the analysis of physical and chemical variables for characterization. We included fecal coliform levels because these bacteria have been used traditionally to assess water quality from a human health perspective. Fecal coliform levels are one of the criteria used in delineating areas closed to shellfishing.

ANALYSIS OF LIVING RESOURCE DATA

For the characterization process, three criteria were used in the selection of living resource variables: economic importance, ecological importance, and availability of data. For these reasons, analysis concentrated on fisheries and submerged aquatic vegetation (SAV).

To identify trends in fisheries, commercial landings were evaluated for sixteen commercially significant species (Table 5). Trends in the juvenile indices for the major commercial species were also assessed to obtain a more objective assessment of abundance. The juvenile index represents annual abundance as the number of 0 age-class fish of a given species per seine haul per river (or Bay area). In addition, juvenile indices for three non-commercial species (mummichog, *Fundulus heteroclitus*; Atlantic silversides, *Menidia menidia*; and Bay anchovy, *Anchoa mitchilli*)

TABLE 5. PRINCIPAL COMMERCIAL FISHERIES SPECIES IN CHESAPEAKE BAY

Common Name	Scientific Name	Total Landing (lbs X 1000 for 1980)
Striped bass	*Morone saxatilus*	2563.3
American oyster	*Crassostrea virginica*	21,958.1
White perch	*Morone americana*	1101.9
Blueback herring[1]	*Alosa aestivalis*	1369.1
Alewife[1]	*Alosa pseudoharengus*	1369.1
Menhaden	*Brevoortia tyrannus*	443,977.6
Croaker	*Micropogon undulatus*	622.1
Bluefish	*Pomatomus saltatrix*	2791.2
Catfish	*Ictalurus sp.*	2265.7
Sea Trout	*Cynocion regalis*	5113.6
Soft Clam	*Mya arenaria*	1925.8
Blue Crab	*Callinectes sapidus*	58,956.5
Yellow Perch	*Perca flavescens*	28.0
Spot	*Leiostomus xanthurus*	1755.3
Shad	*Alosa sapidissima*	903.3
Hard Clam	*Mercenaria mercenaria*	570.7

[1] Combined in landing statistics as Alewife.

were analyzed. An assessment of trends in these three non-commercial estuarine spawners was intended to point out if the trends were influenced by factors other than fishing pressure. Atlantic silversides are heavy users of SAV and could be expected to show effects of SAV loss. Oyster spat set data were analyzed to assess the reproductive potential of the fishery and to provide a parallel with juvenile indices. To obtain an indication of the health of the oyster, condition index and histopathological data were analyzed.

Data bases were selected according to their temporal and spatial completeness (Table 6). The historical records of the various fisheries were obtained from statistical digests of the U.S. Fish and Wildlife Service and the National Marine Fisheries Service, Fishery Statistics of the United States. The single exception is that the Maryland Department of Natural Resources' catch records were used for all finfish in Maryland (except for the Potomac) for the period 1962 to 1980, because these records were more complete. These landings were derived from reports submitted by the commercial fishermen or from surveys taken of the fishermen and/or market houses. The harvest data are complicated by changes in collection methods over the time period of report.

One of the best sets of living resource data (Table 6) concerning Chesapeake Bay is based on an estuarine fish recruitment survey conducted by Joseph B. Boone of the Maryland Department of Natural Resources. This survey of young-of-the-year finfish has been continual and consistent in technique since 1958 for four areas of the Bay including the Nanticoke, Choptank, and the Potomac Rivers, and the head of the Bay (Boone 1980).

The density of annual oyster spat fall (set) is a measure of success of natural oyster reproduction and recruitment and may be an indicator of water quality. The Maryland Department of Natural Resources has been collecting information on the density of oyster spat set in the Maryland portion of Chesapeake Bay since 1939 (Meritt 1977; Davis et al. 1981); the Virginia Institute of Marine Sciences (VIMS) has been collecting similar information since 1946 (Haven et al. 1978). The methodology of oyster spat set data collection is described in more detail by Davis et al. (1981).

VIMS researchers sampled oysters from 1955 to 1981 and developed a Condition Index that compares the meat of an oyster with its theoretical maximum size, the volume of the shell cavity (Haven et al. 1981). Research in Maryland on oyster histopathology was obtained from the Maryland Department of Natural Resources, Marine Animal Disease Laboratory in Oxford, Maryland. Shellfish, including oysters and soft-shell clams, were analyzed for mortality, twenty infectious and non-infectious diseases, and for physiological indicators such as general tissue quality, shell condition, spawn cycle phases, sex ratios, size, and age.

Submerged Aquatic Vegetation

Submerged aquatic vegetation is an important ecological resource that provides food and habitat to major fish species, and has undergone a precipitous decline in the past 10 to 15 years. It was the subject of a major Chesapeake Bay Program research effort (Orth and Moore 1982).

Sparse data are available (Table 6) on distribution and abundance of SAV before 1970 (Orth and Moore 1982). Since 1970, annual surveys of vegetation have been taken by the U.S. Fish and Wildlife Service Migratory Bird and Habitat Research Laboratory (MBHRL). In addition, extensive aerial surveys were made in 1978 (Orth et al. 1979; Anderson and Macomber 1980).

TABLE 6. LIVING RESOURCES DATA BASES

Agency	Temporal Coverage	Data Base Description	Units
NOAA, NMFS USFWS	1880-1981	Fisheries historical landings (Bay-wide)	pounds
NOAA, NMFS	1962-1981	Fisheries landings by basins (NOAA codes)	pounds
MD DNR	1939-1981	Oyster spat set on natural cultch (MD)	spat per bushel
VA VIMS	1946-1981	Oyster spat set on natural cultch (VA)	spat per bushel
MD DNR	1963-1981	Oyster condition index (MD)	rating of meat quality poor to good
VIMS	1955-1981	Oyster condition index (VA)	1) Index no. 3.0 to 7.6 2) Yield of meats per bushel 3) Rating below average to above average
American University (Anderson and Macomber 1980)	Scattered years since 1936	Historical SAV aerial photographs	Vegetation distribution
U.S. FWS	1971-1981	SAV Vegetation Survey	% vegetation coverage
EPA, VIMS, A.U.	1978-1979	SAV Aerial Survey (Quads)	hectares of vegetation/quad
EPA, MDGS, VIMS	1980	Bay Benthic Survey	biomass and community composition
CBL	1970	Patapsco Benthic Survey	biomass and community composition

(continued)

TABLE 6. (Continued)

Agency	Temporal Coverage	Data Base Description	Units
VIMS	1973	Hampton Roads Benthic Survey	biomass and community composition
CBL	1978-1979	Calvert Cliffs Benthic Survey	biomass and community composition

SECTION 4
THE NORTHERN BAY IN HISTORICAL PERSPECTIVE

Contemporary environmental science in the Bay focuses much effort toward explaining the present condition of the system with some hope of predicting the future. To accomplish this goal, it is helpful to examine the past. One important aspect of the Bay's ecology is that continuous human activity has been operating against a background of natural climatic cycles, episodes, and an occasional extreme event such as a hurricane. The Bay ecosystem is dynamic, and our perspective of assimilative capacity can benefit from examining the past with a view to the future.

The time horizon begins at 1600, near the time of the first permanent settlement in Virginia at Jamestown. In the context of extreme events, which may shift the ecological "balance," it is instructive to examine the history of hurricanes in the Bay. Many people remember the impact of Tropical Storm Agnes, especially on the upper Bay, which occurred in June 1972. However, the "Great Hurricane" of 1933 probably resulted in unidentified ecological impacts. Also, the period from 1877 to 1899 was characterized by numerous severe hurricanes (Table 7).[2]

Temperature is also a key ecological variable, and unusual records exist. In June 1816, ice and frost were recorded; July 1836 was noted to be extremely cold. Severe winter ice and freezing conditions were recorded in 1780, 1784, 1899, and as recent as 1977.[3] These extreme events, operating against long-term trends in land-use activity, exemplify the importance of defining spatial and temporal scales when making ecological assessments.

It is equally instructive to recognize that major land "improvements" such as farming were well along by the mid-1700's. The effect on the forested area shows a consequent decrease, followed by a return to the forests by the 1780's, of much of the previously cleared land. Much of this land was devoted to the production of tobacco and general agriculture. From about 1800 onwards, there is a clear and continual trend in the conversion of forests into fields.

Several towns exemplify the capacity of human intervention into natural erosional and sedimentological processes, principally through the clearing of land. Joppatown, Maryland, founded 25.6 km[4] northeast of Baltimore, on the Gunpowder River, was created by the Maryland legislature in 1707 near the head of a wide, deep bay that afforded an excellent harbor (Gottschalk 1945). By 1846, a hundred years after the town had reached its peak development, an above-tidewater delta surface of about 2.4 km long had formed. By 1897, the above tidewater deposits had filled the entire estuary opposite the old wharf; as of the early 1940's, the above-tide deposits had isolated the original town and left it land-locked approximately 2.4 km from open water. A similar story can be told for a

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[2] Personal Communication: "Climatic Events," William Cronin, Chesapeake Research Consortium, 1983.

[3] Personal Communication: "Climatic Events," William Cronin, Chesapeake Research Consortium, 1983.

[4] 1 km = 5/8 mile

TABLE 7. UNUSUAL WEATHER CONDITIONS IN CHESAPEAKE BAY (COURTESY OF WILLIAM CRONIN).

Year	Major Weather Problem
1649	earliest historical record - hurricane
1667	earliest published account - hurricane
1780	severe freezing and ice conditions
1784	severe freezing and ice conditions
1806	severe hurricane
1812	hurricane credited with saving Worcester County from British attack in War of 1812
1816	ice and frost in June
1821	severe hurricane
1836	extremely cold even in July
1877	severe hurricane
1879	severe hurricane
1881	severe hurricane
1882	severe hurricane
1886	rare June-July hurricane
1887	severe hurricane
1894	severe hurricane
1897	severe hurricane
1899	extremely cold winter, hurricane
1902	two tropical storms
1920	severe hurricane in February
1926	one of Maryland's severest tornados
1928	severe hurricane
1933	"The Great Hurricane of 1933" - greatest damage recorded to that time.
1936	severe hurricane
1944	two hurricanes - both severe
1954	Hurricane Hazel - severe
1955	two severe hurricanes two weeks apart - Connie and Diane
1960	July gale Brenda and severe hurricane Donna
1962	The "Great March Storm" was not classified as a hurricane - it was called a long-lasting tropical storm - and did some $250,000,000 damage from Florida to New England.
1967	The most unusual hurricane of record - Doria with an extremely erratic path.
1972	Hurricane Agnes - up to 18 inches of rain flooded the major tributaries with the Susquehanna averaging 15.5 times normal flow. Sediment loads reached 1000 mg L^{-1} - normally 10 mg L^{-1}. Soft clams and oysters suffered heavy mortalities. Total economic losses in Maryland and Virginia totaled $42,741,900.
1977	severe icing conditions in Bay
1978	severe icing conditions in Bay
1979	Hurricane David
1982	coldest January on record

number of early commercial centers around the Bay and tidal tributaries, including Port Tobacco, Maryland, on the Potomac River; Bladensburg, Maryland, near Washington, DC; and the upper tidal Patuxent River.

The metal supply to the Bay began to increase considerably about the time of the Civil War, marking the early stages of the Industrial Revolution. This knowledge provides a background to possible exposures of Bay organisms to these potentially toxic materials. Evidence suggests that the metal load to the Bay peaked shortly after World War II. Thus, one might hypothesize that the benthic communities in certain regions of the upper Bay have experienced higher than natural exposure to some heavy metals.

Bottom sediment cores from Furnace Bay located on the northern shore of Susquehanna Flats provide good insights into the history of submerged aquatic vegetation and diatoms (microscopic algae that leave behind a shell formed from silica) (Brush and Davis 1982). These single-celled algae help us make inferences about nutrient conditions at the time they were deposited. Apparently, at around 1720 the SAV species shifted dominance; the formerly dominant waterweed and pondweed became sporadic, with wild celery becoming abundant. Changes were noted in the epiphytic algae that grow on the leaves and stems of SAV. During this period of initial land clearing, many diatoms became less abundant, and a few species disappeared as the shallow waters became more turbid. This was the first clear signal that nutrient enrichment was probably occurring. The recent dramatic decline of SAV is a phenomenon whose magnitude in the Bay has no parallel over the past 380 years.

There is evidence that important changes have occurred in freshwater runoff. The peak flows in rivers have increased by as much as 30 percent during the last two hundred years (Biggs 1981). Additional evidence, concerning changes in freshwater flow and salinity, is provided by an analysis of Foraminifera, a group of benthic shelled Protozoa, which have representative species that are sensitive to the salt content of bottom waters (Nichols 1982). These changes are believed to be related to deforestation. Climatic variables, such as those indicated by rainfall and temperature records for Philadelphia beginning in 1738 (Landsberg and Yu 1968), do not correlate with the fresh-salt pattern, thus providing evidence that the relatively rapid cycles of fresh and salt conditions are likely the result of human intervention.

Fisheries are of direct concern to people, and it is noteworthy that the first published records began in 1880. Note that the harvest has fluctuated over the period of record. Marine spawners have dominated the record. Anectodal information suggests that the availability of various fish species have changed over time. For example, as early as 1629, Captain John Smith reported that the near-shore fishery was not so abundant as in 1607 to 1608.

From a research perspective, the earliest nutrient data were taken in the late 1930's by scientists working out of the Chesapeake Biological Laboratory. The laboratory, the oldest state-supported research facility on the East Coast, was not founded until 1925. Hydrographic work at the Chesapeake Bay Insititue, The Johns Hopkins University, only began about 1949, and the Virginia Fisheries Laboratory, now the Virginia Institute of Marine Science, first conducted work about 1940. The first comprehensive nutrient survey in the northern Bay did not occur until 1964. These institutions represent the earliest major research focus on the Bay, but this period of 30 to 50 years is brief compared to the prior history of change. However, interest in oysters stimulated early studies beginning in the latter 1880 and 1890's (Brooks 1891).

This brief summary leaves an indelible impression. The Bay has been interacting in imperfect ways with natural events, hurricanes and cycles of climatic change. But more importantly, human activity made some marked impacts on the Bay by the mid-1700's; however, the most significant impacts were initiated in the mid-1800's and reached high levels around World War II. The past 40 years have been a time of new events for the Bay -- some possibly not coded into the genetic memory of the Bay species, including man, and the accompanying chlorinated hydrocarbons and excessive metal and nutrient enrichment. An observation of considerable importance is the relatively short period of scientific research on the Bay relative to the period of impact by human activity. Interdisciplinary work that focuses on questions of interest to society is of very recent origin.

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INDIVIDUAL RESEARCH PROJECTS

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Historical Review of Water Quality and Climatic Data from Chesapeake Bay with Emphasis on Effect of Enrichment

Water Quality Monitoring of the Three Major Tributaries to the Chesapeake Bay

Ware River Intensive Watershed Study

Evaluation of Management Tools in the Occoquan Watershed

Effects of Specific Land Uses on Nonpoint Sources: Pequea Creek Basin, 1979-1980

Chesapeake Bay Nutrient Dynamics

Patuxent River Intensive Watershed Study

TOXIC SUBSTANCES

The Characterization of the Chesapeake Bay: A Systematic Analysis of Toxic Trace Elements

Fate, Transport, and Transformation of Toxics: Significance of Suspended Sediment and Fluid Mud

Dredging: Implementation of Innovative Dredging Techniques in the Chesapeake Bay

Physical Characteristics and Sediment Budget for Bottom Sediments in the Maryland Portion of Chesapeake Bay

Animal/Sediment Relationships

Chesapeake Bay Sediment Trace Elements

The Biogenic Structure of Lower Chesapeake Bay Sediments

Interstitial Water Chemistry

Toxic Point Source Assessment of Industrial Discharges

Interpretation of Toxic Substances in the Water Column

SUBMERGED AQUATIC VEGETATION

Distribution and Abundance of Submerged Aquatic Vegetation in the Lower Chesapeake Bay, Virginia

Distribution of Submersed Vascular Plants, Chesapeake Bay, Maryland

Distribution and Abundance of Waterfowl and Submerged Aquatic Vegetation in Chesapeake Bay

The Biology and Propagation of Eelgrass, *Zostera marina*, in Chesapeake Bay

Sediment Suspension and Resuspension from Small Craft Induced Turbulence

Interactive Studies of Light, Epiphytes, and Grazers

Changes in the Chesapeake Bay as Recorded in the Sediments

Propagation and Impact of Herbicides on Submerged Aquatic Vegetation

Functional Ecology of Submerged Aquatic Vegetation

Submerged Aquatic Vegetation in Chesapeake Bay - Its Role in the Bay Ecosystem and Factors Leading to Its Decline

ENVIRONMENTAL MANAGEMENT

Review of Regional Water Quality Control

Evaluation of Institutional Arrangements

SECTION 6

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SECTION 1
BASIN FEATURES AND CLIMATIC CONDITIONS

GEOGRAPHY

Chesapeake Bay is the drowned river valley of the Susquehanna River. It was formed approximately 10,000 years ago when melting glacial ice resulted in a sea level rise that submerged the Susquehanna River Valley. The Bay is approximately 322 kilometers (km)[1] long with 12,872 km of shoreline and a surface area of about 11,391 km^2 (2) including its tributaries. The volume, surface area, and average depth of the Chesapeake Bay Program segments were computed using a planimeter and bathymetric chart and are shown in Tables 1 to 3. On the basis of this analysis, the average depth of the Bay and its tributaries is 6.63 meters (m)[3]. Eastern Shore segments are the shallowest areas (3.68 m average depth), and the main Bay segments CB-4 to CB-8 have the deepest average depths (10.92 m to 7.83 m).

CLIMATE

Meteorologic conditions in the Chesapeake Basin influence the hydrodynamics of the Bay and drive its circulation. Table 4 summarizes the 1980 air temperature, precipitation, and general wind conditions in Baltimore, MD, compared with the norm, means, and extremes from past years. The monthly average air temperatures ranged from -0.3°C[4] in February to 25.9°C in August. Precipitation varied from 17.78 millimeters (mm)[5] in December to 13.87 centimeters (cm)[6] in March. Winds throughout the year were generally from the northwest or west.

A longer-term perspective on climate can be found by looking at the 1900 to 1980 air temperature records for representative areas in the basin including Baltimore, MD, Washington, DC, and Harrisburg, PA (Figure 1). It appears from visual observation that localized air temperatures in Washington, DC, at National Airport have increased slightly, perhaps because of increased urbanization. This trend does not appear in the Harrisburg or Baltimore data, probably because their stations are located outside of the downtown, highly urbanized area. Figure 2 shows that over the period of record, average summer air temperatures range in the 70's (degrees Fahrenheit), fall and spring temperatures in the 50's (degrees Fahrenheit), and winter temperatures in the 30's (degrees Fahrenheit).

FRESHWATER INFLOW

The three major tributaries of the Bay system are the Susquehanna, Potomac, and James Rivers. Together these three rivers drain about 70

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[1] 1 km = 5/8 mile

[2] 1 km^2 = 0.386 mi^2

[3] 1 m = 3.3 ft

[4] 1 °C = 5/9(°F - 32)

[5] 1 mm = 0.04 in

[6] 1 cm = 0.39 in

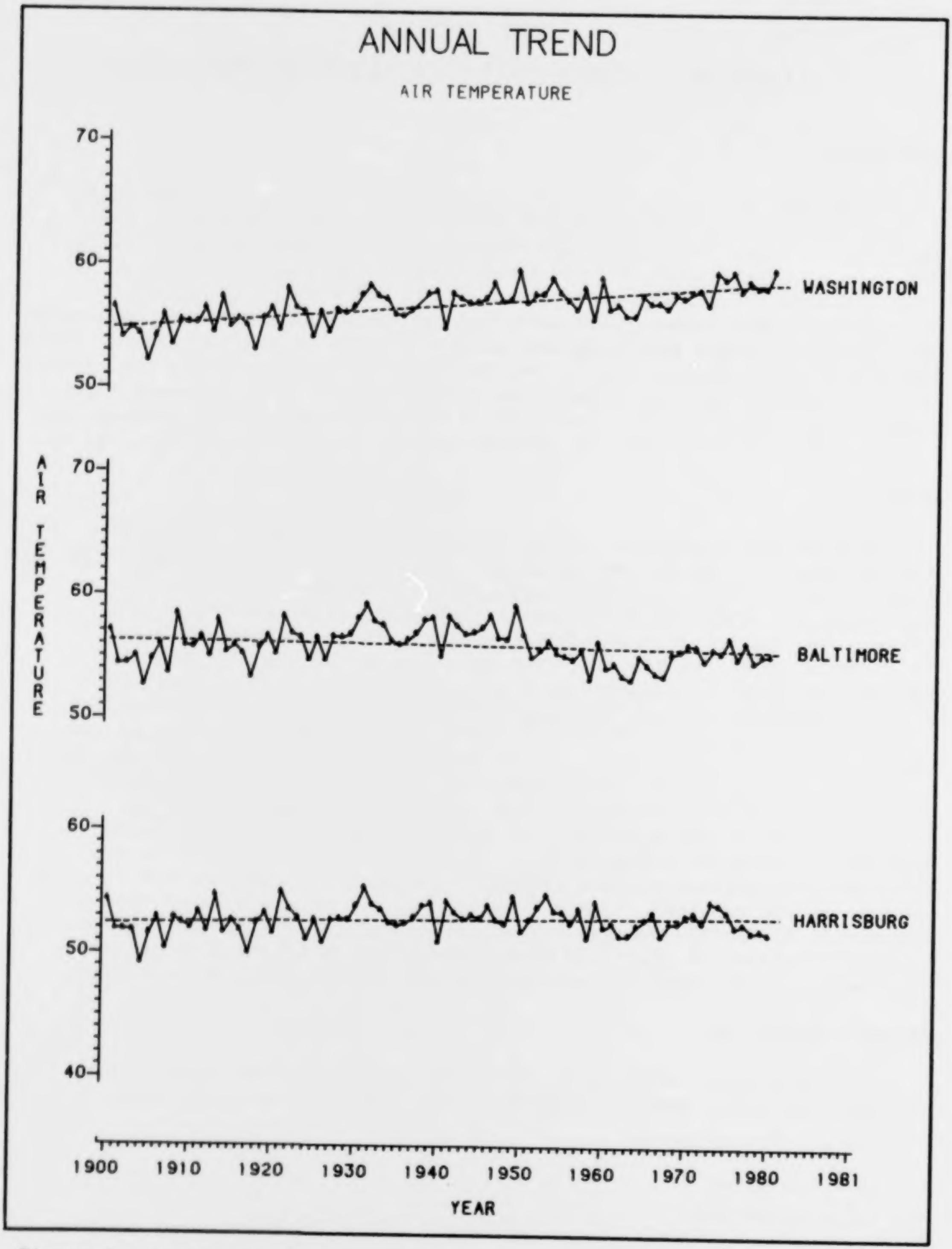

Figure 1. Long term air temperature (in fahrenheit) (50 degrees F = 10 degrees centigrade).

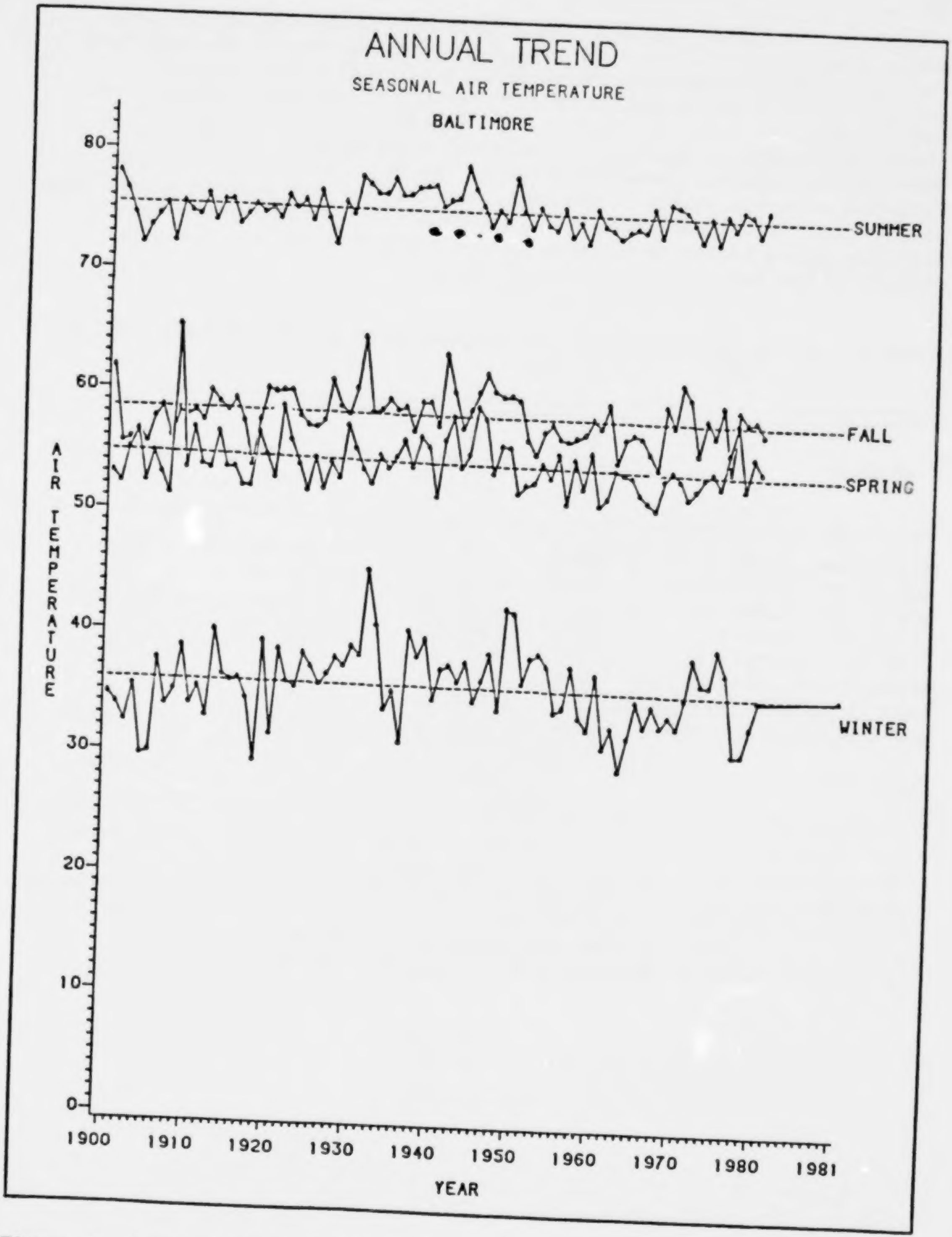

Figure 2. Average seasonal air temperature (in fahrenheit) in Baltimore, Maryland (50 degrees F = 10 degrees centigrade).

percent of the approximately 64,000 square mile Chesapeake Bay drainage basin (Figure 3) and account for about 80 to 85 percent of the long-term average freshwater discharge Bay-wide (Wolman 1968). The long-term, average annual flows from 1950 to 1980 for the Susquehanna, Potomac, and James Rivers are shown in Figure 4. Pritchard (1967) notes that the freshwater flow from the Susquehanna alone significantly affects the physical and chemical characteristics of the Bay. As a result of this influence, the Bay proper is moderately stratified with surface waters less saline than the bottom waters. The greatest vertical difference in salinity occurs in the riverine-estuarine transition area in the upper section of the Bay.

TABLE 1. VOLUME, SURFACE AREA, AND AVERAGE DEPTH OF CBP SEGMENTS* IN THE MAIN BAY

SEGMENT	CBP SEGMENT CODE	VOLUME ($10^6 m^3$)	SURFACE AREA ($10^6 m^2$)	AVER. DEPTH (m)
SUSQUEHANNA FLATS	CB-1	175.41	106.93	1.64
TURKEY PT - ROBINS PT	CB-2	712.62	173.36	4.11
ROBINS PT - SANDY PT	CB-3	2499.59	425.00	5.88
SANDY PT - COVE PT	CB-4	9388.88	859.91	10.92
COVE PT - WINDMILL PT	CB-5	16485.81	1748.47	9.43
WINDMILL PT - NORTHEND PT	CB-6	6965.74	756.85	9.20
TANGIER ISLAND - BAY MOUTH	CB-7	11701.70	1304.93	8.97
NORTH END PT - BAY MOUTH	CB-8	3122.38	398.87	7.83
TOTAL		51052.13	5774.32	8.84

*Total area and volume were calculated by summing values given for each one-mile interval in Volumetric, Areal, and Tidal Statistics of the Chesapeake Bay and Its Tributaries, Cronin (1971). For those segments and portions of segments having boundaries that did not correspond with Cronin's intervals, the area and volume were planimetered from a bathymetric chart of Chesapeake Bay (Goldsmith and Sutton 1977).

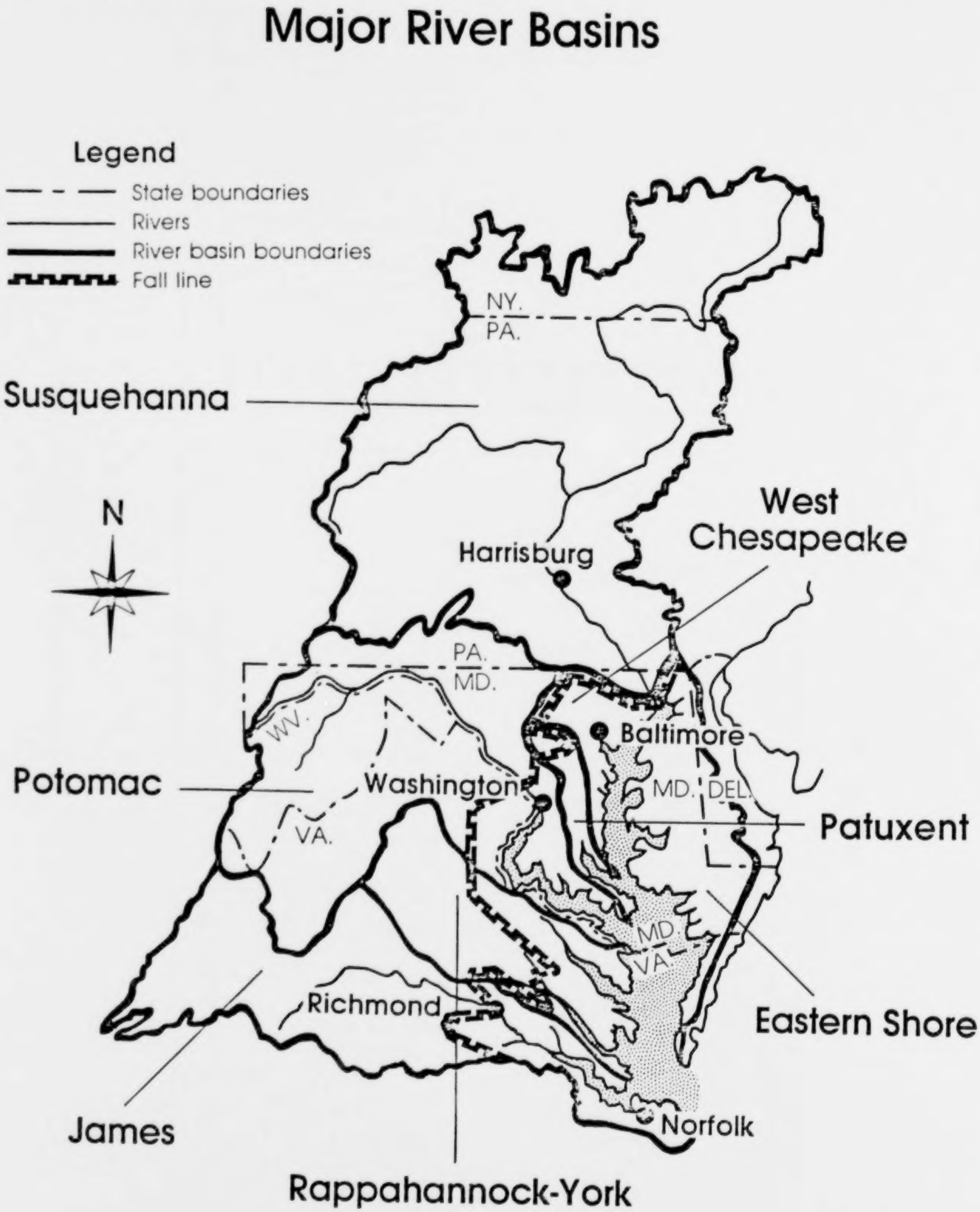
Major River Basins
Legend
State boundaries
Rivers
River basin boundaries
Fall line
NY.
PA.
Susquehanna
N
Harrisburg
West Chesapeake
PA.
MD.
WV.
Baltimore
Potomac
Washington
MD.
DEL.
Patuxent
VA.
MD.
VA.
Eastern Shore
Richmond
Norfolk
James
Rappahannock-York

Figure 3. Chesapeake Bay drainage basin.

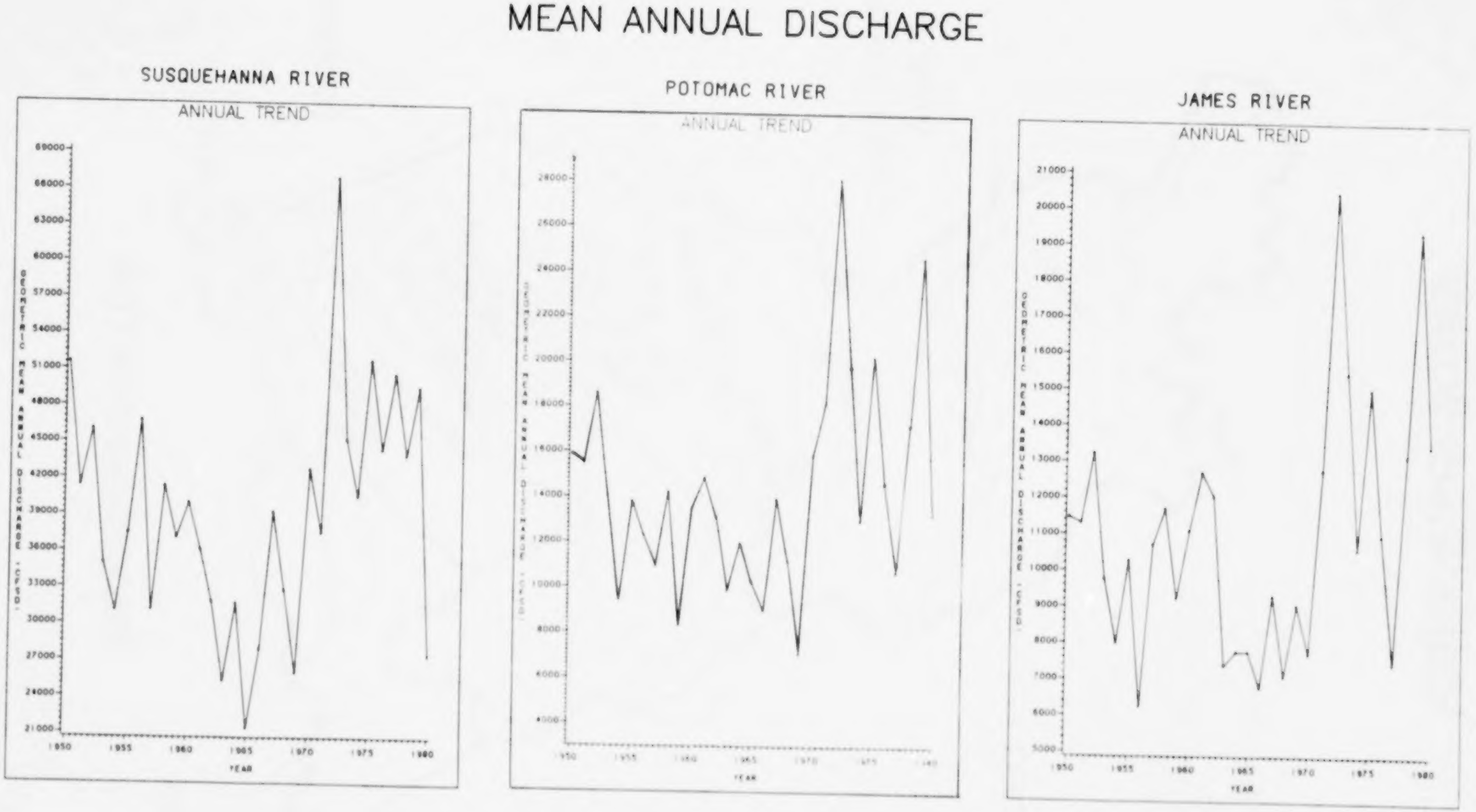

Figure 4. Freshwater discharge for major rivers.

TABLE 2. VOLUME, SURFACE AREA, AND AVERAGE DEPTH OF CBP SEGMENTS OF THE WESTERN SHORE TRIBUTARIES

SEGMENT	CBP SEGMENT CODE	VOLUME ($10^6 m^3$)	SURFACE AREA ($10^6 m^2$)	AVER. DEPTH (m)
BUSH RIVER	WT-1	60.50	33.22	1.82
GUNPOWDER RIVER	WT-2	74.86	45.37	1.65
MIDDLE RIVER, SENECA CREEK	WT-3	47.21	24.75	1.91
BACK RIVER	WT-4	34.55	18.57	1.86
PATAPSCO RIVER	WT-5	467.40	100.41	4.65
MAGOTHY RIVER	WT-6	89.85	25.89	3.47
SEVERN RIVER	WT-7	130.03	30.32	4.29
WEST RIVER RHODE RIVER SOUTH RIVER	WT-8	122.55	47.32	2.59
PATUXENT RIVER				
lower	LE-1	521.29	103.53	5.04
middle	RET-1	34.02	17.71	1.92
upper	TF-1	4.34	0.99	4.38
POTOMAC RIVER				
lower	LE-2	5640.20	862.52	6.54
middle	RET-2	968.25	223.49	4.33
upper	TF-2	679.59	165.47	4.11
RAPPAHANNOCK RIVER				
lower	LE-3	1339.17	233.58	5.73
middle	RET-3	254.23	105.63	2.41
upper	TF-3	214.97	60.87	3.53
MOBJACK BAY - YORK RIVER MOUTH	WE-4	1420.13	363.98	3.90
YORK RIVER				
lower	LE-4	522.56	108.60	4.81
middle	RET-4	123.74	45.62	2.71
upper	TF-4	175.95	41.21	4.27
JAMES RIVER				
lower	LE-5	1769.00	464.55	3.81
middle	RET-5	308.54	98.46	3.13
upper	TF-5	429.44	95.19	4.51
TOTAL		15432.37	3317.25	4.65

TABLE 3. VOLUME, SURFACE AREA, AND AVERAGE DEPTH OF CBP SEGMENTS OF THE EASTERN SHORE

SEGMENT	CBP SEGMENT CODE	VOLUME $(10^6 m^3)$	SURFACE AREA $(10^6 m^2)$	AVER. DEPTH (m)
NORTHEAST RIVER	ET-1	18.80	15.79	1.19
ELK RIVER	ET-2	106.84	47.22	2.26
SASSAFRAS RIVER	ET-3	168.31	36.51	4.61
CHESTER RIVER	ET-4	533.36	147.06	3.63
EASTERN BAY	EE-1	1160.99	258.84	4.49
CHOPTANK RIVER				
lower	EE-2	1194.96	348.24	3.43
upper	ET-5	457.99	99.67	4.60
TANGIER SOUND	EE-3	3923.47	1002.75	3.91
NANTICOKE RIVER	ET-6	173.48	67.18	2.58
WICOMICO RIVER	ET-7	67.59	33.17	2.04
MANOKIN RIVER	ET-8	104.59	68.18	1.53
BIG ANNEMESSEX RIVER	ET-9	51.10	29.33	1.74
POCOMOKE RIVER	ET-10	29.50	16.50	1.74
TOTAL		7990.98	2170.44	3.68

Meteorological Data For The Current Year

Station: BALTIMORE, MARYLAND # 93721 BALTIMORE-WASHINGTON INTL AP Standard time used: EASTERN Latitude 39° 11' N Longitude 76° 40' W Elevation (ground): 148 feet Year 1980

Month	Temperature °F Averages Daily maximum	Averages Daily minimum	Averages Monthly	Extremes Highest	Date	Extremes Lowest	Date	Degree days Base 65 °F Heating	Cooling	Precipitation in inches Water equivalent Total	Greatest in 24 hrs.	Date	Snow, Ice pellets Total	Greatest in 24 hrs.	Date	Relative humidity pct. Hour 01 (Local time)	Hour 07	Hour 13	Hour 19	Wind Resultant Direction	Resultant Speed m.p.h.	Average speed m.p.h.	Fastest mile Speed m.p.h.	Fastest mile Direction	Fastest mile Date	Percent of possible sunshine	Average sky cover, tenths, sunrise to sunset	Number of days Sunrise to sunset Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog, visibility ¼ mile or less	Temperature °F Maximum 90° and above (b)	Maximum 32° and below	Minimum 32° and below	Minimum 0° and below	Average station pressure mb. Elev. [illegible] feet m.s.l.
JAN	40.5	27.1	33.8	54	16	17	24	962	0	2.58	1.08	19	4.7	3.5	4-5	65	64	55	61	32	5.1	9.2	[illegible]	W	24	41	7.4	5	8	18	9	2	0	2	0	[illegible]	24	0	1013.1
FEB †	40.6	22.3	31.5	62	21	8	29	967	0	1.06	0.27	22	7.8	2.0	28	80	84	44	48	33	6.1	9.7	31	W	27	†64	4.9	13	6	10	9	2	0	2	0	6	25	0	1012.4
MAR	51.0	31.9	41.5	70	8	11	1	723	0	5.46	1.61	13-14	5.7	4.7	1-2	88	69	51	57	30	3.4	11.6	41	W	14	58	7.0	8	5	18	16	2	2	1	0	2	15	0	1010.8
APR	66.3	45.1	55.7	79	20	28	17	273	0	4.24	1.74	26-27	0.0	0.0		67	73	48	54	32	1.4	9.4	33	NW	4	48	5.8	9	9	12	12	0	5	4	0	0	1	0	1007.8
MAY	76.6	54.4	65.5	88	13	38	4	74	47	3.58	0.85	30-1	0.0	0.0		75	75	50	61	29	2.1	8.7	32	NW	14	54	5.9	10	7	14	14	0	5	1	0	0	0	0	1007.4
JUN	83.1	59.3	71.3	95	27	47	9	6	201	3.04	1.19	7	0.0	0.0		74	71	40	51	27	4.1	8.1	47	NW	24	73	5.0	11	10	9	7	0	5	0	5	0	0	0	1009.4
JUL	89.2	67.1	78.2	102	16	53	7	0	415	3.25	1.13	21-22	0.0	0.0		72	71	44	56	24	3.1	7.4	36	NW	22	72	4.0	17	10	4	10	0	4	3	14	0	0	0	1009.1
AUG	89.1	68.1	78.7	99	8	58	17	0	431	4.00	1.21	10-11	0.0	0.0		74	79	48	63	25	2.7	6.5	39	NW	3	61	5.2	8	16	7	9	0	6	0	19	0	0	0	1011.7
SEP	83.5	60.9	72.2	98	2	40	27	20	245	1.00	0.44	24-25	0.0	0.0		76	80	45	61	25	0.7	6.9	32	NW	26	70	4.8	10	12	8	7	0	0	2	8	0	0	0	1012.5
OCT	65.9	44.7	55.3	83	2	31	31	311	17	3.08	1.71	24-25	0.0	0.0		73	78	47	64	28	3.5	8.1	31	W	26	61	5.3	11	11	9	7	0	0	1	0	0	2	0	1010.8
NOV	53.9	34.4	44.2	71	7	25	21	620	0	2.72	1.16	17-18	T	T	27	56	71	48	57	29	5.4	9.1	34	NW	11	51	5.3	10	9	11	6	0	1	2	0	0	15	0	1012.9
DEC	44.7	26.2	35.5	74	8	5	26	908	0	0.70	0.27	24	0.2	0.1	31	62	65	48	56	30	4.5	9.1	47	W	1	47	6.6	7	7	17	7	0	0	3	0	8	22	0	1015.6
YEAR	65.4	45.1	55.3	102	JUL 16	5	DEC 26	4864	1406	34.71	1.71	OCT 24-25	18.4	4.7	MAR 1-2	70	72	47	58	29	3.1	8.8	47	NW	JUN 24	61	5.6	119	110	137	116	6	32	15	46	21	104	0	1011.1

† DATA CORRECTED AFTER PUBLICATION OF THE MONTHLY ISSUE.

Normals, Means, And Extremes

Month	Temperatures °F Normal Daily maximum	Normal Daily minimum	Normal Monthly	Extremes Record highest	Year	Record lowest	Year	Normal Degree days Base 65 °F Heating	Cooling	Precipitation in inches Water equivalent Normal	Maximum monthly	Year	Minimum monthly	Year	Maximum in 24 hrs.	Year	Snow, Ice pellets Maximum monthly	Year	Maximum in 24 hrs.	Year	Relative humidity pct. Hour 01 (Local time)	Hour 07	Hour 13	Hour 19	Wind Mean speed m.p.h.	Prevailing direction	Fastest mile Speed m.p.h.	Fastest mile Direction	Fastest mile Year	Pct. of possible sunshine	Mean sky cover, tenths, sunrise to sunset	Mean number of days Sunrise to sunset Clear	Partly cloudy	Cloudy	Precipitation .01 inch or more	Snow, Ice pellets 1.0 inch or more	Thunderstorms	Heavy fog, visibility ¼ mile or less	Temperatures °F Max. 90° and above (b)	Max. 32° and below	Min. 32° and below	Min. 0° and below	Average station pressure mb. Elev. [illegible] feet m.s.l.
(a)				30		30					30		30		30		30		30		27	27	27	27	30	11	30	30		30	30	30	30	30	30	30	30	30	30	30	30	30	[illegible]
J	41.9	24.4	33.4	75	1975	-7	1963	980	0	2.91	7.84	1979	0.29	1955	3.11	1976	21.4	1966	12.1	1966	68	71	59	62	9.3	WNW	63	NE	1958	51	6.3	8	6	15	10	2	*	*	0	6	25	*	1012.[illegible]
F	43.9	25.7	34.8	76	1976	-3	1979	846	0	2.81	7.15	1979	0.56	1978	2.18	1971	33.3	1979	20.0	1979	66	71	61	58	10.5	NW	68	W	1956	56	6.1	8	7	13	9	2	*	*	0	*	22	*	1012.7
M	53.0	32.5	42.8	87	1979	6	1960	688	0	3.69	6.90	1953	0.93	1966	3.18	1958	21.6	1967	19.0	1962	66	71	53	55	11.1	WNW	80	SE	1952	56	6.4	8	8	14	11	2	1	1	0	*	15	0	1011.[illegible]
A	65.2	42.4	53.8	94	1960	20	1965	348	0	3.07	8.11	1952	1.26	1978	2.83	1952	2.4	1964	2.4	1964	68	72	48	51	10.8	WNW	70	W	1954	56	6.1	8	9	13	11	*	2	2	*	0	3	0	1010.[illegible]
M	74.6	52.5	63.7	98	1962	32	1966	110	10	3.41	7.10	1960	0.47	1964	5.64	1960	T	1961	T	1961	73	77	51	60	9.4	W	65	SW	1961	56	6.7	8	10	13	11	0	4	2	1	0	*	0	1009.[illegible]
J	83.2	61.4	72.4	100	1959	40	1972	0	225	3.77	9.95	1972	0.15	1954	5.25	1972	0.0		0.0		81	87	53	62	8.6	WNW	80	SW	1952	62	5.7	8	12	10	9	0	6	1	6	0	0	0	1010.7
J	86.7	65.5	76.6	102	1980	51	1979	0	360	4.07	9.14	1969	0.30	1955	5.86	1952	0.0		0.0		81	81	57	63	8.0	W	57	SW	1962	64	5.6	7	12	12	9	0	6	1	11	0	0	0	1010.7
A	85.1	64.7	74.9	102	1951	48	[illegible]	0	307	4.21	18.35	1955	0.77	1951	7.62	1955	0.0		0.0		84	86	56	67	8.0	W	54	NE	1955	62	5.6	10	10	11	10	0	5	1	7	0	0	0	1012.[illegible]
S	79.0	57.9	68.5	98	1962	35	1963	27	117	3.12	8.62	1971	0.21	1967	4.92	1976	0.0		0.0		83	85	56	69	8.2	S	56	W	1952	60	5.3	11	9	10	7	0	2	2	2	0	0	0	1012.[illegible]
O	68.1	46.4	57.4	92	1954	25	1969	250	14	2.81	8.09	1976	T	1963	7.40	1955	0.3	1979	0.3	1979	74	82	54	67	8.8	NW	73	SE	1954	58	5.1	11	9	11	7	0	1	3	*	0	0	0	1013.[illegible]
N	56.1	36.0	46.1	83	1974	13	1955	567	0	3.11	7.65	1952	0.51	1976	3.49	1952	8.4	1967	8.4	1967	73	77	55	64	9.4	WNW	58	S	1952	51	6.0	9	8	13	9	*	*	1	0	*	11	0	1015.[illegible]
D	43.9	26.6	35.5	74	1980	3	1960	921	0	3.24	7.49	1969	0.20	1955	3.34	1969	20.4	1960	14.1	1960	70	74	58	64	9.4	WNW	57	W	1953	49	6.3	9	7	15	9	1	*	*	0	4	21	*	1015.[illegible]
YR	65.1	44.8	55.0	102	JUL 1980	-7	JAN 1963	4729	1108	40.46	18.35	AUG 1955	T	OCT 1963	7.62	AUG 1955	33.3	FEB 1979	20.0	FEB 1979	75	77	54	62	9.3	W	80	SW	JUN 1952	57	5.9	109	109	147	113	7	28	24	31	15	99	*	1011.[illegible]

Means and extremes above are from existing and comparable exposures. Annual extremes have been exceeded at other sites in the locality as follows: Highest temperature 107 in July 1936; maximum monthly snowfall 33.9 in February 1899; maximum snowfall in 24 hours 24.5 in January 1922.

TABLE 4. METEOROLOGICAL DATA FOR BALTIMORE, MD. (NOAA 1980)

SECTION 2
WATER QUALITY AND SEDIMENT SAMPLING STATIONS

WATER QUALITY STATIONS

The CBP water quality data base contains sampling data for physical and chemical constituents in Bay waters and tributaries from 1949 through 1981 at the sites indicated in Figure 5.

Figure 6 indicates sites which were sampled at least once a month for fecal coliforms from 1976 to 1980 in Maryland. The Patuxent River basin has coverage from 1970 to 1980. In Virginia, there are from 3 to 50 sampling stations indicated in each of 98 shellfish growing areas. Data were available for 1974, 1975, and 1980.

Bottom sediments were collected for the Bay Program during the spring and fall of 1979. Analyses revealed over 300 organic compounds from stations shown in Figure 7.

Samples from the water column were analyzed for organic compounds, heavy metals, and pesticides. Samples were collected at stations shown in Figure 8 from 1962 through 1981. Figure 9 shows sediment sampling stations for the same time period.

Shellfish tissue was analyzed for heavy metals, organic compounds, and pesticides. Stations sampled from 1962 through 1981 are shown in Figure 10.

SPATIAL SAMPLING

To provide a dynamic picture of Bay-wide water quality over the entire period of record, only those samples taken in representative stations were selected for comparison. Data from shallow, near-shore stations were not used to calculate regional averages, nor were samples taken in deep ($>$ 10 m) channels. Most of the samples used for analysis were taken over deeper waters associated with the main-Bay channel.

The greatest number of observations were present in the upper central Bay, between Poole's Island and Cove Point. In CB-3, sampling was concentrated closer to the western and eastern shores where greater depths coincide with two ancient river beds. Farther south, in CB-4, the two depressions converge in a deeper mid-Bay channel. In this segment, most samples were collected mid-Bay over deeper water. In the south Bay (CB-5), most samples were taken in the western half where the main channel is closer to the western shore. General Bay, CB-6, CB-7, and Bay mouth CB-8 stations were generally distributed closer to the Eastern Shore in proximity to deeper waters.

TEMPORAL COVERAGE

For CBP segments where three or more stations were sampled in any one month, monthly water quality means were calculated. Seasonal means were calculated for segments with at least two of three monthly means available. Annual means were calculated for segments with two or more seasonal means available in the same year.

The distribution of stations for which DO, TN, TP and Chl a data exists varies over time. Prior to 1961, little data were available to calculate annual and seasonal means for CBP segments. Summer means were calculated for TP in the main Bay, the Bay mouth, and parts of the York and

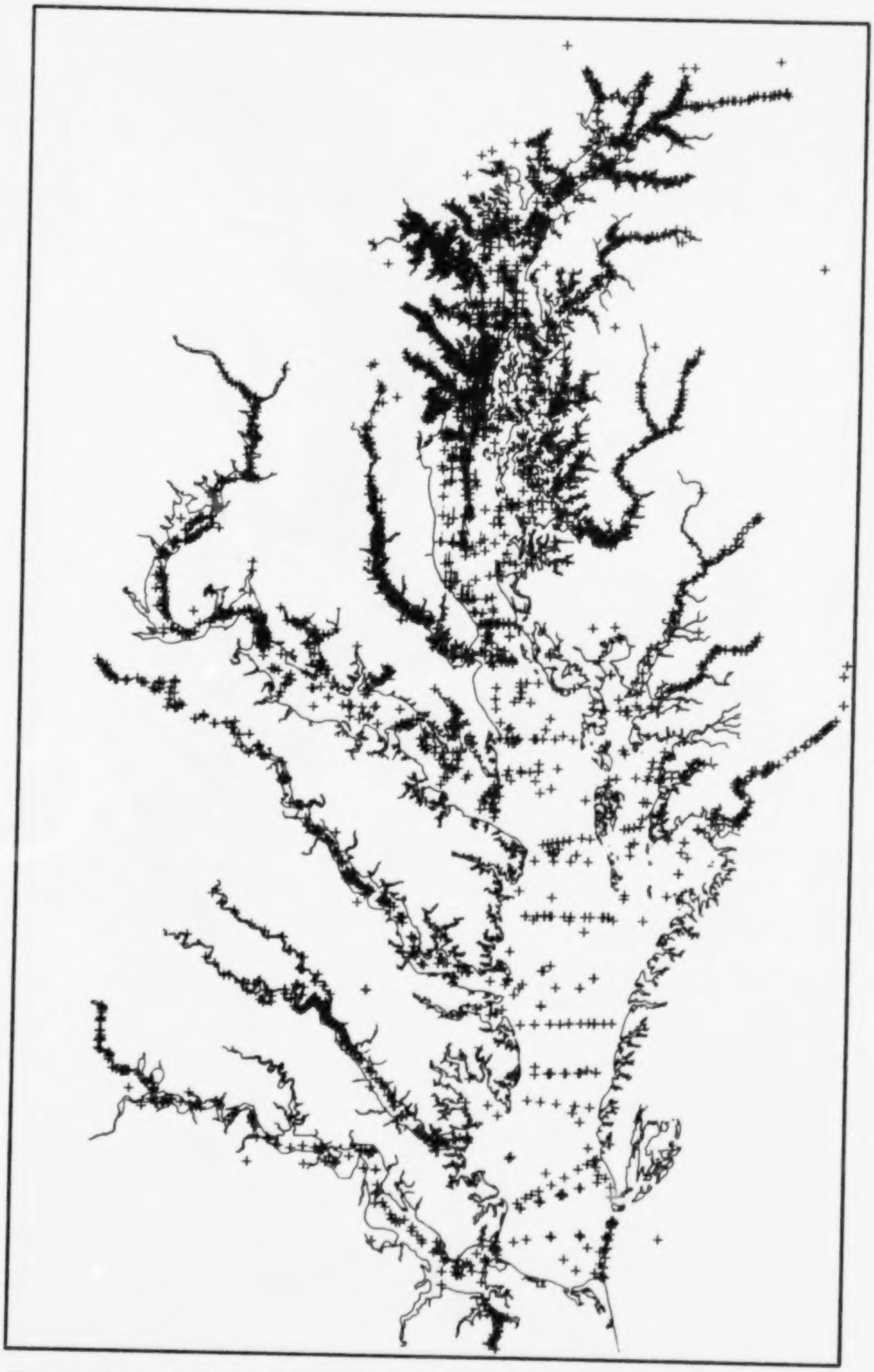

Figure 5. Chesapeake Bay water quality sampling station.

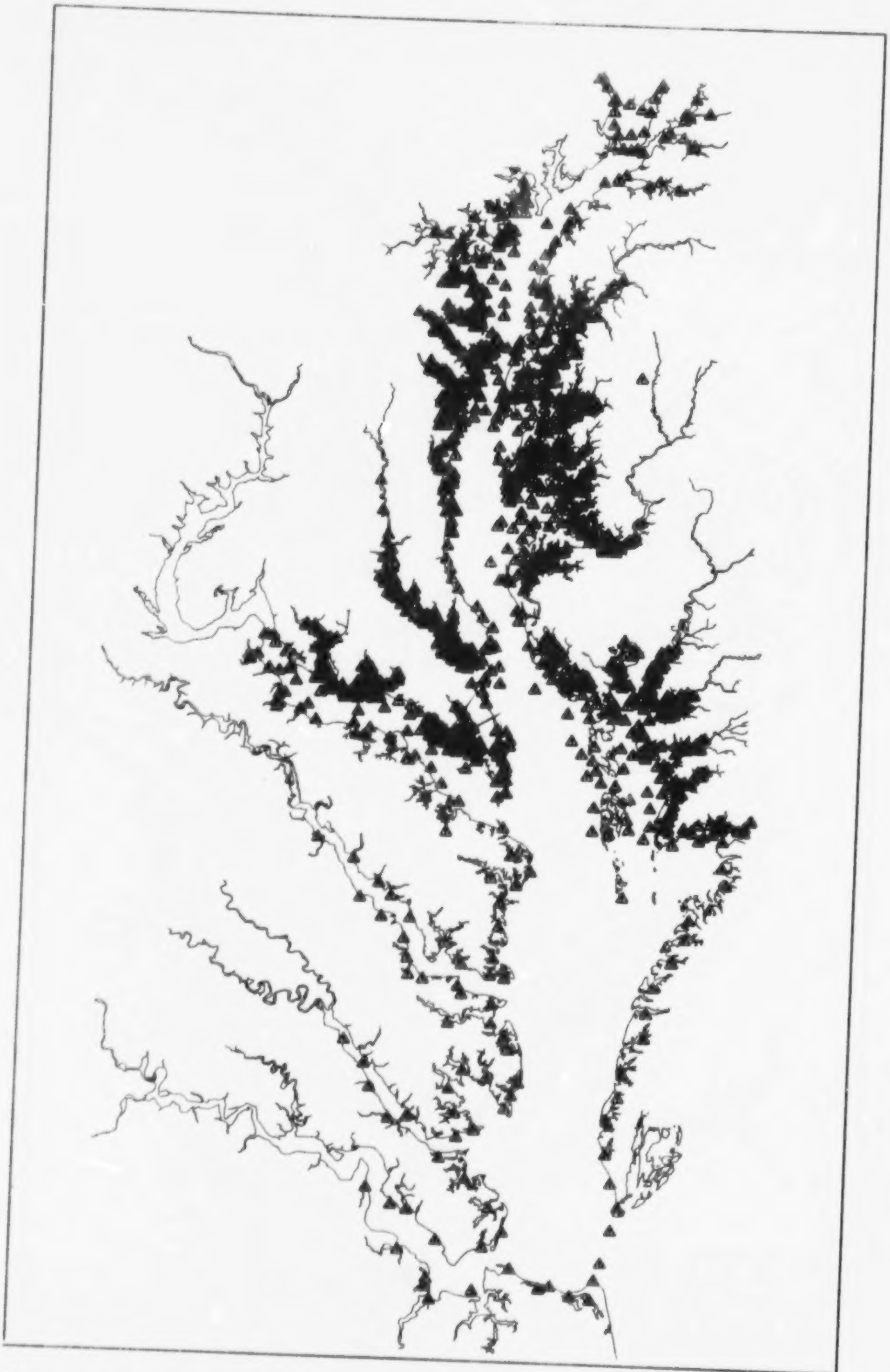

Figure 6. Fecal coliform sampling stations.

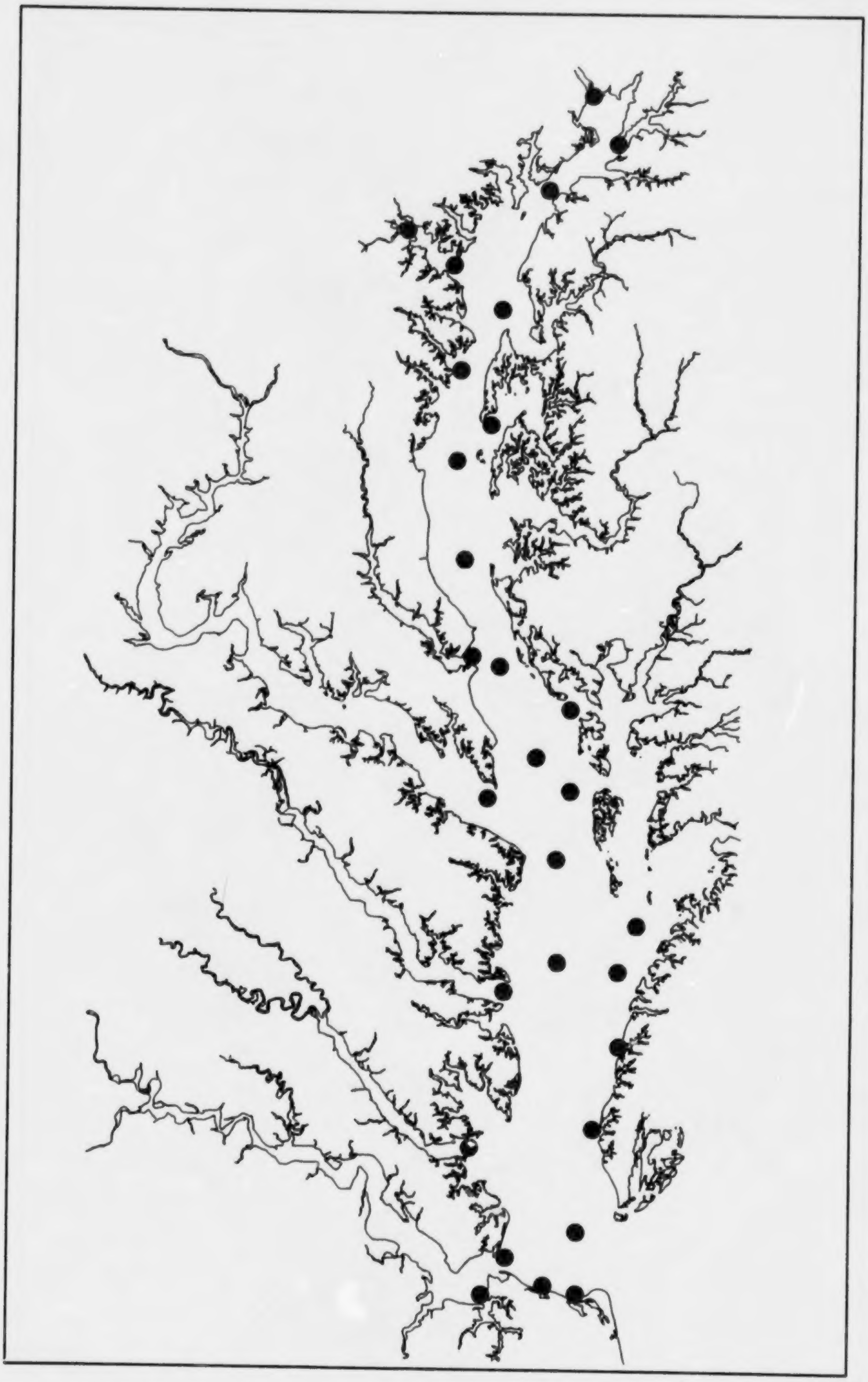

Figure 7. Chesapeake Bay organic compound sampling stations.

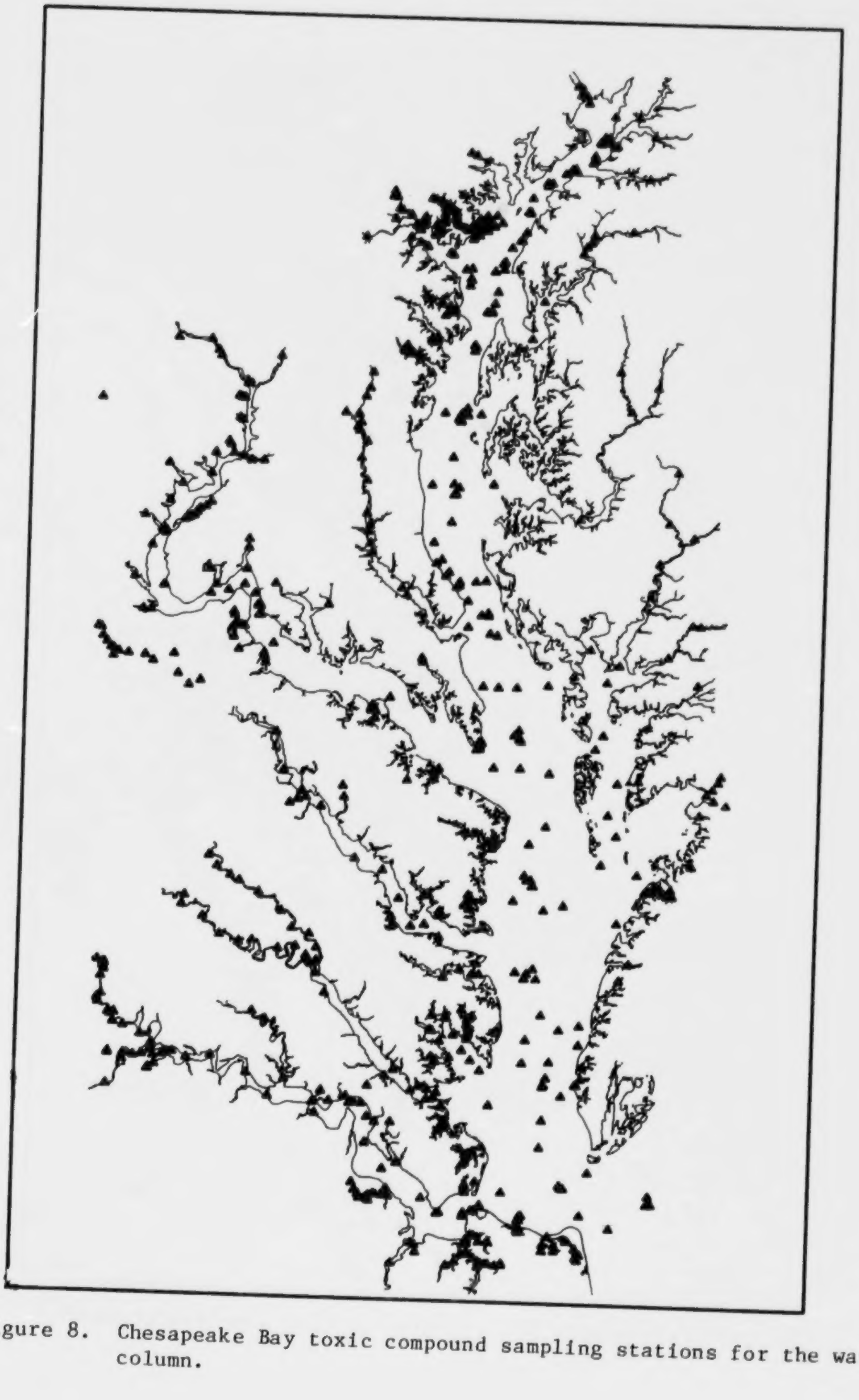

Figure 8. Chesapeake Bay toxic compound sampling stations for the water column.

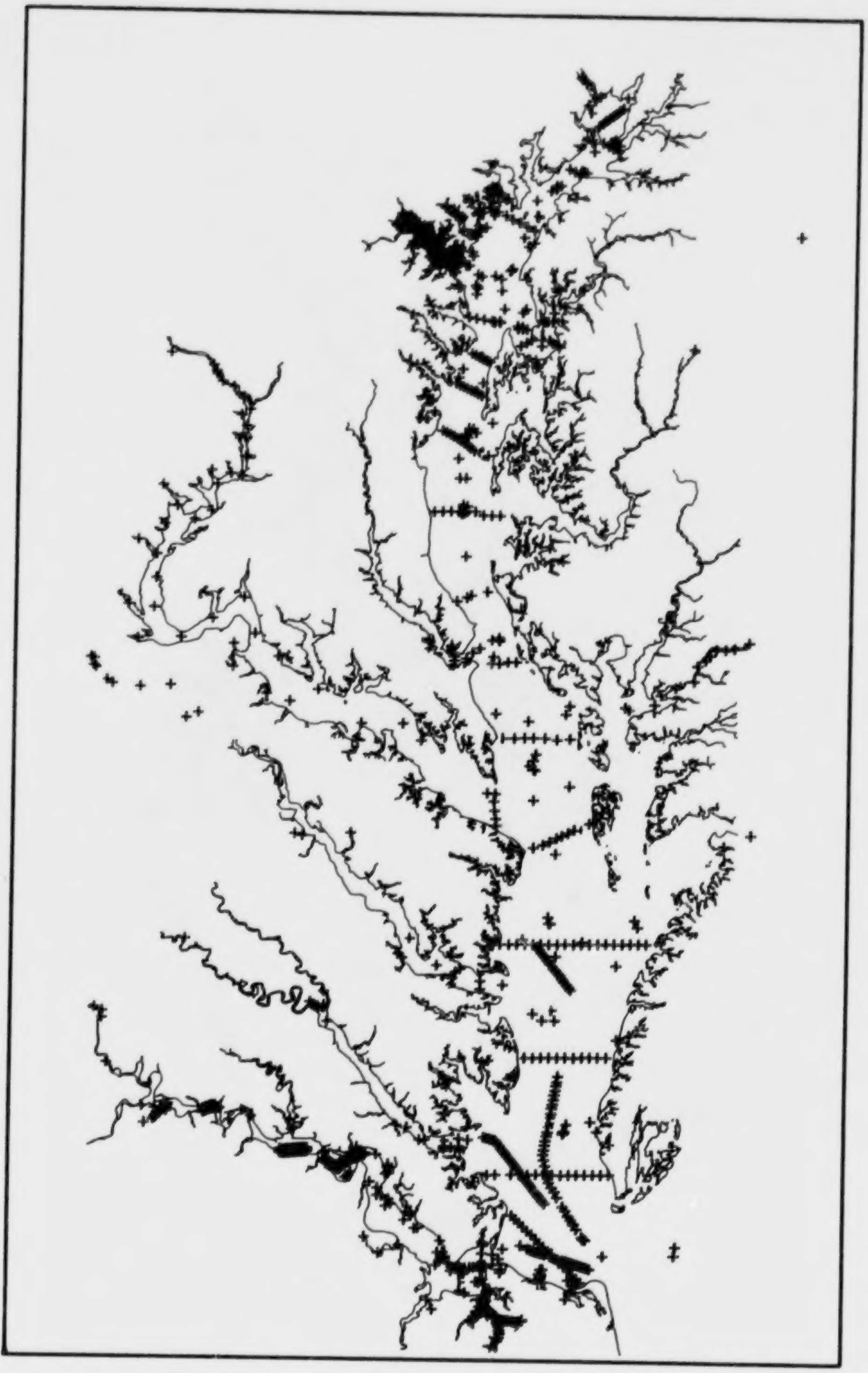

Figure 9. Sampling stations for toxic bottom sediments in Chesapeake Bay.

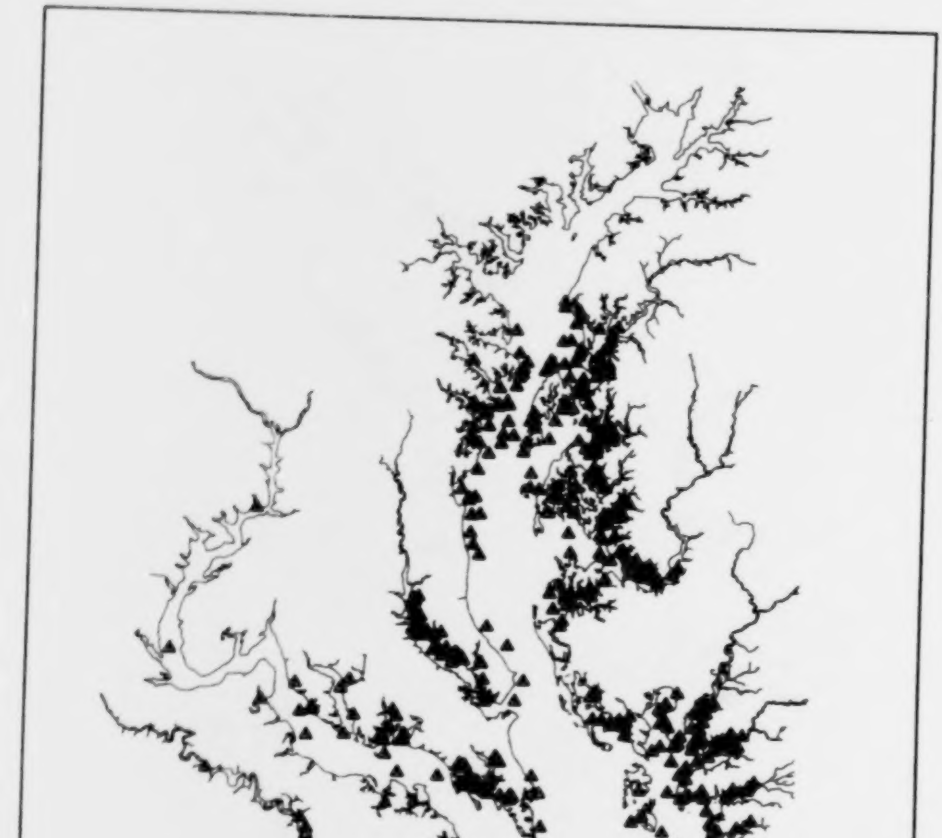

Figure 10. Chesapeake Bay stations for sampling shellfish tissue.

Rappahannock Rivers. Summer DO means were available for CB-5, and portions of the York, Potomac, and Patuxent Rivers. Annual DO means were available for CB-5 only.

Summer and annual TP means during 1961 to 1965 were well distributed in the upper Bay and all of the Potomac River, Chester River, and Eastern Bay. Dissolved oxygen (DO) was again available in CB-5 only.

More complete coverage exists for the upper Bay, CB 1-3, from 1966 to 1970 for TP and, DO including the upper Patuxent River, Potomac River, Eastern Bay, secondary western tributaries, and a limited portion of the upper James. The first TN data became available for the same regions, except Eastern Bay.

During 1971 to 1975 coverage of the main Bay extended down to the mouth of the Potomac for TP and TN. Most secondary western tributaries and the upper Bay were covered; however, sampling in major tributaries was spotty. No TP or TN means are available for the Patuxent or lower Potomac. Eastern tributaries were covered, including the Wicomico and Pocomoke Rivers. Again, DO means were limited, especially on an annual basis, to portions of the upper Bay (CB-3), upper Potomac, York, and lower Rappahannock, York and James Rivers.

For 1976 through 1980, summer TP and TN means are fairly complete as far south as the Potomac River and include most secondary tributaries. Coverage includes all major tributaries, except the mid- and lower Rappahannock. Data on summer DO, again, were limited to the main Bay, CB-3, Patuxent River, upper and mid-Potomac, and lower York and James Rivers. Noticeably less annual means were available during 1976 to 1980, indicating that seasonal sampling was not balanced throughout those years.

SECTION 3
EPA WATER QUALITY CRITERIA APPLIED TO METALS IN THE BAY

INTRODUCTION

Heavy metal concentrations that surpass the EPA water quality criteria are found primarily in the main Bay and western shore tributaries. Monitoring data on toxic substances shows that the abundance of heavy metals appears to be related to the concentration of population centers. The highest water column metal concentrations in Maryland are in the Potomac River with zinc (Zn) in the fresh portion and copper (Cu) in the estuarine, in Baltimore Harbor Cu, Zn, and in the main Bay between the Gunpowder River and Cove Point [Cu, cadmium (Cd), chromium (Cr), Zn] (Figures 11 and 12). In Virginia, the estuarine segments of the Rappahannock, York, and James Rivers contain levels of nickel (Ni) and Cu that exceed both acute and chronic criteria. A similar pattern exists for the western half of the main Bay in Virginia.

DERIVATION AND BASIS OF WATER QUALITY CRITERIA

The EPA National Water Quality Criteria shown in Table 5 establish maximum constituent concentrations below which organisms, aquatic communities, water uses, and water quality are adequately protected. The criteria are intended to protect aquatic life from short-term (acute) and long-term (chronic) effects (U.S. EPA Water Quality Criteria 1980).

They are derived from laboratory data that, excluding endemic environments or species, are generally applicable to comparable field situations throughout North America. The limits are intended to protect all the environments without being overly restrictive. Although criteria are usually derived separately from freshwater and salt water environments, similar acute-chronic ratios and bioaccumulation factors allow interchangeable criteria.

Criteria, which are not intended to be overall limits, are frequently used in the development of effluent standards. Standards establish a legal limit and are designed to consider environmental, social, economic, and other specific local conditions.

USING THE WATER QUALITY CRITERIA

The criteria, developed from measured effects under laboratory conditions, are based on toxicological "no effect" concentrations and reflect the soluble, biologically available fraction of the metal. Therefore, only those field measurements reported as "dissolved" can be properly compared to the criteria (Table 6). The majority of the data, reported as "total," cannot be compared in that form. The dissolved fraction of those field measurements (Kingston 1982) have been estimated by using equations developed by CBP researchers (Chapter 1). The results of the "calculated dissolved" data are shown in Table 7. These fractions are our best estimate of what is potentially available to Bay biota.

Both the "dissolved" and "calculated dissolved" data were compared to the appropriate salt water or freshwater criteria and reported for both

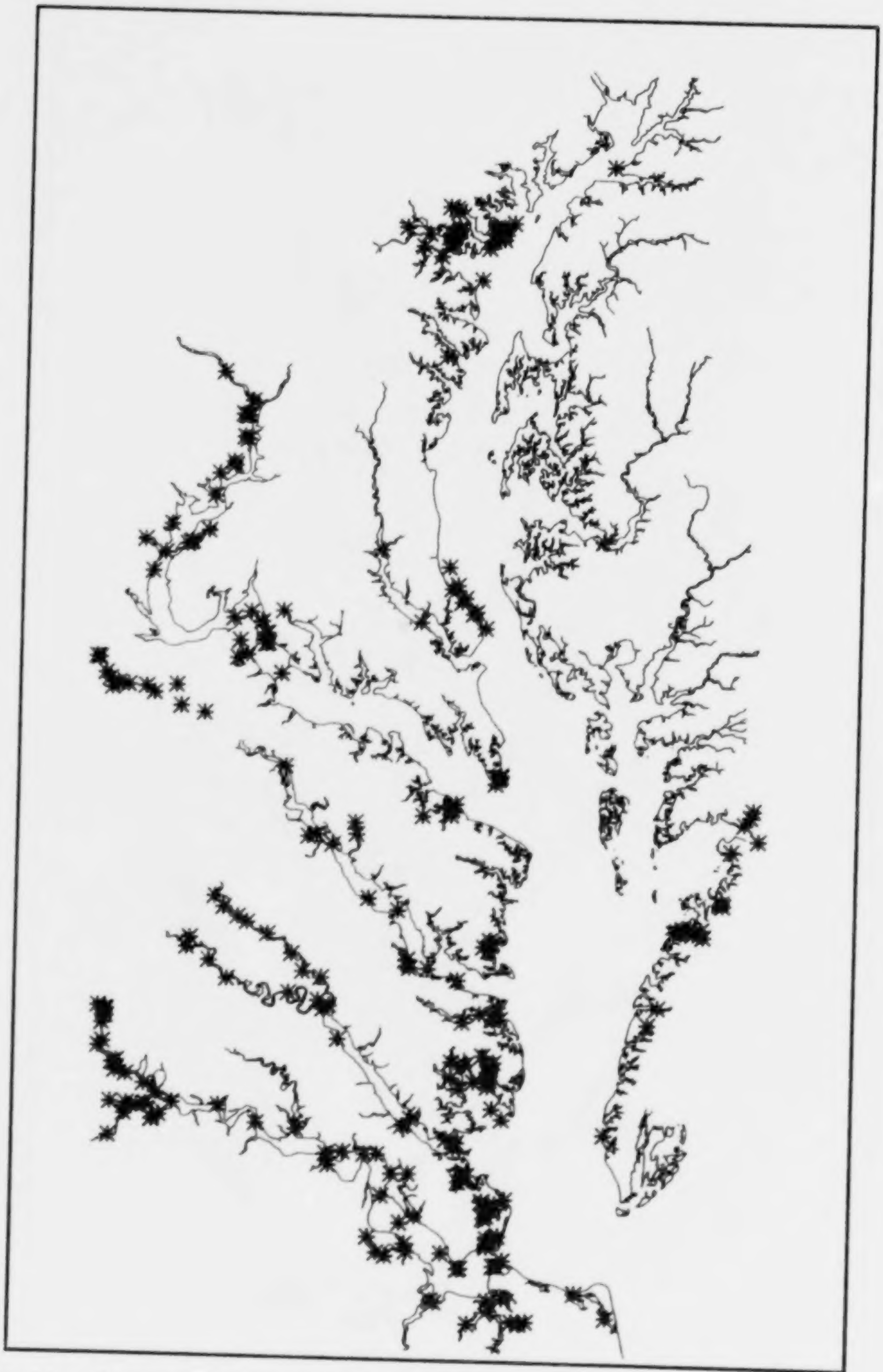

Figure 11. Dissolved metals violations of EPA water quality criteria in Chesapeake Bay before 1971 to 1975.

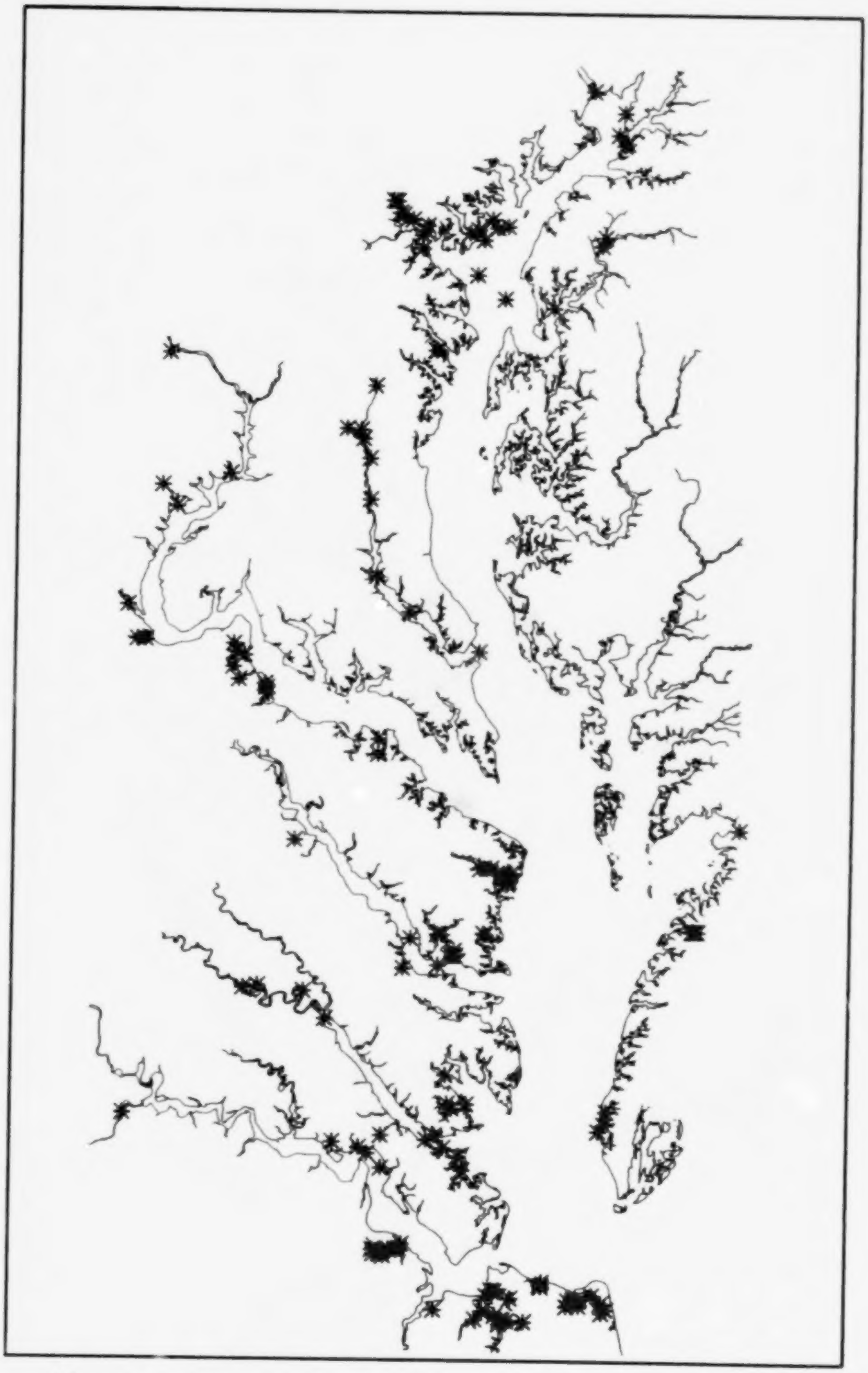

Figure 12. Dissolved metals violations of EPA water quality criteria in Chesapeake Bay after 1975.

chronic and acute toxicity (Tables 6, 7, and 8).

Chronic toxicity refers to behavioral or physiological stresses placed upon the individual or reproductive failure within the species. Although toxicant levels may not be immediately harmful for initial generations or consumers, subsequent bioaccumulation can create irreversible effects. These criteria consider the metal's accumulation, persistence, and effects in aquatic systems.

Acute toxicity, generally based on 48 to 96 hour exposures, refers to the lethal concentration for a specific percentage of test organisms.

TABLE 5. U.S. EPA WATER QUALITY CRITERIA (FROM U.S. EPA 1980)

	Aquatic Life			
	Freshwater		Salt water	
Metal	Chronic	Acute	Chronic	Acute
Cd	(a)	(b)	4.5 u	59.u
Cr^{+3}	-	(c)	-	-
Cr^{+6}	.29 u	21.u	18.u	1260.u
Cu	5.6 u	(d)	4.0 u	23.u
Pb	(e)	(f)	-	-
Ni	(g)	(h)	7.1 u	140.u
Zn	47.u	(i)	58.u	170.u

		Example: at $CaCo_3$ hardness of:	
		50 m	200 m
(a)	e exp (1.05 [ln hardness] - 8.52)*	.012 u	.051 u
(b)	e exp (1.05 [ln hardness] - 3.73)	1.5 u	6.3 u
(c)	e exp (1.08 [ln hardness] + 3.48)	2200. u	9900. u
(d)	e exp (0.94 [ln hardness] - 1.23)	12. u	43. u
(e)	e exp (2.35 [ln hardness] - 9.48)	.75 u	20. u
(f)	e exp (1.22 [ln hardness] - 0.47)	74. u	400. u
(g)	e exp (0.76 [ln hardness] + 1.06)	56. u	160. u
(h)	e exp (0.76 [ln hardness] + 4.02)	1100. u	3100. u
(i)	e exp (0.83 [ln hardness] + 1.95)	180. u	570. u

*e(1.05 [ln hardness] - 8.52)

TABLE 6. DISSOLVED METAL VIOLATIONS (SOURCE: VA 106)

Segment	Metal	Observations	Violations			
			Acute	%	Chronic	%
Potomac						
TF-2	Nickel	5	1	20	1	20
LE-2	Nickel	13	3	23	13	100
Rappahannock						
TF-3	Nickel	2	1	50	1	50
RET-3	Nickel	1	0		1	50
LE-3	Nickel	12	5	42	12	100
York						
TF-4	Nickel	7	3	43	7	100
RET-4	Nickel	10	0		10	100
LE-4	Nickel	19	9	47	18	95
James						
RET-5	Nickel	2	0		2	100
LE-5	Nickel	75	29	39	75	100
Eastern Shore						
ET-10	Nickel	1	0		1	100

TABLE 7. "CALCULATED" DISSOLVED METAL VIOLATIONS (SOURCE: MD 106, VA 106)

Segment	Metal	Observations	Violations			
			Acute	%	Chronic	%
MAIN BAY						
CB-2	Cadimium	1	1	100	1	100
CB-3	Lead	235	0		0	
	Nickel	371	0		1	1
	Cadmium	326	1	1	1	1
	Chromium (Cr^3)	376	0		22	6
	Chromium (Cr^6)	376	6	2	22	6
	Copper	378	8	2	47	12
	Zinc	378	1	1	17	4
CB-4	Cadmium	111	0		12	11
	Chromium (Cr^3)	107	0		0	
	Chromium (Cr^6)	107	0		0	
	Copper	111	5	5	30	27
	Zinc	111	0		0	
CB-5	Lead	107	0		1	1
	Cadmium	62	0		10	16
	Chromium (Cr^3)	52	0		1	2
	Chromium (Cr^6)	52	0		1	2
	Copper	119	4	3	73	61
	Zinc	117	0		2	2
CB-7	Lead	111	0		1	1
	Cadmium	11	0		11	100
	Copper	96	11	11	96	100
	Zinc	80	0		3	4
CB-8	Lead	71	0		1	1
	Cadmium	5	0		5	100
	Copper	64	13	20	64	100
	Zinc	74	0		1	1
WESTERN SHORE						
WT-2	Lead	28	0		0	
	Cadmium	28	0		0	
	Chromium (Cr^3)	28	0		0	
	Chromium (Cr^6)	28	0		0	
	Copper	28	0		0	
	Zinc	29	0		0	
WT-4	Lead	64	0		0	
	Cadmium	67	0		0	
	Chromium (Cr^3)	65	0		1	2
	Chromium (Cr^6)	65	0		1	2
	Copper	64	0		0	
	Zinc	66	1	2	2	3
WT-5	Lead	86	1	1	7	8
	Nickel	76	0		0	
	Cadmium	87	1	1	7	8
	Chromium (Cr^3)	130	0		4	3

(continued)

TABLE 7. (continued)

Segment	Metal	Observations	Violations			
			Acute	%	Chronic	%
	Chromium (Cr^6)	130	1	1	4	3
	Copper	86	7	8	12	14
	Zinc	95	4	4	21	22
WT-6	Lead	10	0		0	
	Nickel	8	0		0	
	Cadmium	10	0		0	
	Chromium (Cr^3)	8	0		0	
	Chromium (Cr^6)	8	0		0	
	Copper	10	0		0	
	Zinc	10	0		0	
WT-7	Copper	29	1	3	6	21
WT-8	Copper	10	0		0	
Patuxent						
TF-1	Lead	274	0		0	
	Cadmium	274	1	1	1	1
	Chromium (Cr^3)	274	0		5	2
	Chromium (Cr^6)	274	0		5	2
	Copper	275	3	1	4	1
	Zinc	275	1	1	3	1
Potomac						
TF-2	Lead	37	0		2	5
	Nickel	28	0		0	
	Cadmium	37	0		0	
	Chromium (Cr^3)	34	0		3	9
	Chromium (Cr^6)	34	0		3	9
	Copper	32	0		0	
	Zinc	37	0		24	65
RET-2	Lead	15	0		0	
	Cadmium	97	6	6	6	6
	Chromium (Cr^3)	90	0		3	3
	Chromium (Cr^6)	90	2	2	3	3
	Copper	92	0		13	14
	Zinc	96	0		0	
LE-2	Lead	5	0		0	
	Nickel	2	0		2	100
	Cadmium	63	4	6	18	29
	Chromium (Cr^3)	51	0		0	
	Chromium (Cr^6)	51	0		0	
	Copper	121	13	11	82	68
	Zinc	174	0		4	2

(continued)

TABLE 7. (continued)

Segment	Metal	Observations	Violations			
			Acute	%	Chronic	%
Rappahannock						
LE-3	Cadmium	3	0		2	67
	Copper	103	15	15	102	99
	Zinc	113	4	4	14	12
York						
LE-4	Cadmium	12	0		9	75
	Copper	80	8	10	80	100
	Zinc	90	0		2	2
James						
LE-5	Lead	545	0		3	1
	Cadmium	17	2	12	15	88
	Chromium (Cr^3)	301	0		1	1
	Chromium (Cr^6)	301	0		1	1
	Copper	376	66	18	376	100
	Zinc	476	5	1	27	6
WE-4	Cadmium	8	0		8	100
	Copper	189	13	7	189	100
	Zinc	156	5	3	13	8
EASTERN SHORE						
ET-2	Lead	27	1	4	1	4
	Cadmium	27	0		0	
	Chromium (Cr^3)	27	0		0	
	Chromium (Cr^6)	27	0		0	
	Copper	27	2	7	2	7
	Zinc	27	1	4	2	7
ET-4	Lead	10	0		2	20
	Cadmium	10	2	20	2	20
	Chromium (Cr^3)	10	0		0	
	Chromium (Cr^6)	10	0		0	
	Copper	10	1	10	6	60
ET-5	Cadmium	1	0		1	100
EE-3	Lead	1	0		0	
	Cadmium	4	0		3	75
	Chromium (Cr^3)	1	0		0	
	Chromium (Cr^6)	1	0		0	
	Copper	23	0		22	96
	Zinc	1	0		0	
ET-10	Cadmium	1	0		1	100
	Copper	24	1	4	24	100
	Zinc	39	1	3	1	3

TABLE 8. DISSOLVED METAL VIOLATIONS (SOURCE: N.B.S. 1980)

Segment	Metal	Observations	Violations			
			Acute	%	Chronic	%
MAIN BAY						
CB-1	Lead	4	0		0	
	Nickel	4	0		0	
	Cadmium	4	0		0	
	Chromium (Cr^3)	4	0		2	50
	Chromium (Cr^6)	4	0		2	50
	Copper	4	0		2	50
	Zinc	4	0		0	
CB-2	Lead	4	0		0	
	Nickel	4	0		0	
	Cadmium	4	0		0	
	Chromium (Cr^3)	4	0		1	25
	Chromium (Cr^6)	4	0		1	25
	Copper	4	0		1	25
	Zinc	4	0		0	
CB-3	Lead	6	0		0	
	Nickel	6	0		0	
	Cadmium	6	0		0	
	Chromium (Cr^3)	6	0		4	67
	Chromium (Cr^6)	6	0		2	33
	Copper	6	0		2	33
	Zinc	6	0		0	
CB-4	7 metals	14	No violations			
CB-5	7 metals	24	No violations			
CB-6	7 metals	8	No violations			
CB-7	7 metals	20	No violations			
CB-8	7 metals	4	No violations			
EE-1	7 metals	2	No violations			
EE-2	7 metals	2	No violations			
EE-3	7 metals	8	No violations			
WE-4	7 metals	4	No violations			

DATA SOURCES

Ambient water quality monitoring data have been gathered by the States bordering Chesapeake Bay and by the Chesapeake Bay Program itself.

The Virginia State Water Control Board data base (Virginia 106) contains data on dissolved nickel in the lower Bay and its tributaries. These data are shown in Table 6, both as amounts and as percentages of all observations.

"Total" metals have been collected and combined in STORET, the EPA's environmental data base, since the 1960's. Data from both VA 106 and MD 106 have been used to calculate the "dissolved" phase and are shown in Table 7.

Samples collected by the National Bureau of Standards (N.B.S.) are shown in Table 8. This 1982 research project (Kingston 1982) analyzed dissolved metal concentrations in the main Bay using neutron activation analysis.

RESULTS

In addition to the main Bay, areas most highly enriched with metals are the Potomac River, Baltimore Harbor, the estuarine segments of the western shore tributaries, and the Pocomoke Sound region.

Throughout the main Bay, there are chronic criteria violations for Cu and, below Cove Point, chronic criteria violations for Cd, Cu, and Ni.

The entire Potomac River is enriched -- the tidal-fresh portion by Zn and the lower sections by Cu. More than 10 percent of the Cu samples in the lower-estuarine portion exceed acute criteria.

The chronic criteria for Cu and Zn are exceeded more than 14 percent of the time in Baltimore Harbor. Twelve percent of the samples from the adjacent portion of Chesapeake Bay exceed chronic criteria.

The Rappahannock, York, and James Rivers in Virginia have been sampled primarily in the lower estuarine portion. Chronic criteria levels for Cu and Ni are exceeded virtually 100 percent of the time in these rivers and in Mobjack Bay. In the lower James, the chronic criteria for Cd is exceeded in 88 percent of the samples. The acute criteria for Cu and Ni are exceeded in 18 percent and 39 percent of the samples.

Ninety-eight percent of the samples from the Pocomoke River and Pocomoke Sound were above the chronic criteria for Cu. This estuarine zone is adjacent to Tangier Sound, one of the sections of Chesapeake Bay least impacted by anthropogenic activity.

CONCLUSIONS

The EPA water quality criteria were developed from laboratory toxicity tests based largely upon the ionic forms of the heavy metals, even though metals in an estuarine environment may be in such forms as carbonates, ligands, complexes, hydroxides, or adsorbed to suspended organic and mineral materials. Although criteria used for Chesapeake Bay are from national values, it is possible that heavy metals threaten Chesapeake Bay biota, especially in the western tributaries and the main Bay. This potential could be better evaluated if the extent and duration of these high concentrations were identified.

Further analysis should consider the applicability of national standards to Chesapeake Bay, the temporal and spatial distribution of those values exceeding the standards, and the usefulness of establishing site-specific criteria for the Bay. In Chapter 3, the implications of water quality criteria for Bay organisms is discussed further.

SECTION 4

THE DERIVATION OF SITE-SPECIFIC WATER QUALITY CRITERIA FOR EIGHT METALS IN CHESAPEAKE BAY

The development of site-specific water quality criteria by the states will be possible under proposed changes by EPA to its current policy of presumptive applicability. Currently, a state must adopt the national water quality criterion for all water quality characteristics unless the state can justify a less stringent criterion [40 CFT Part 131, Section 304(a)].

The following site-specific salt water criteria developed by the CBP (using EPA's recalculation procedure) are similar to the more general national criteria. Truely accurate site-specific criteria should be developed by conducting toxicity tests with resident species and site water (Parrish 1983).

THE RECALCULATION PROCEDURE

Site-specific water quality criteria for eight metals [arsenic (As), cadmium (Cd), chromium (Cd), copper (Cu), lead (Pb), mercury (Hg), nickel (Ni), and zinc (Zn)] in Chesapeake Bay have been derived by using the recalculation procedure (Parrish 1983). This procedure allows modification of the national criteria acute toxicity data set by eliminating species or families not represented by species resident at a site. It is meant ". . . to compensate for any real difference between the sensitivity range of species represented in the national data set and species resident to the site. The principal reason for potential differences is that the resident communities of a site may represent a more narrow mix of species because of natural environmental conditions (e.g., salinity, temperature, habitat, and other factors)" (U.S. EPA 1982a).

On the basis of monitoring data that show excursions above national criteria for eight metals in the Bay, and on the basis of the complexity of the Bay, this analysis considers eight metals and divides the Bay into two sites based on salinity. Site-specific criteria are derived for those areas where salinity is generally $<$ 10 ppt and those where salinity is generally $\geq$ 10 ppt.

It is limited to evaluation and derivation of criteria for salt water organisms in estuarine and marine environments. In addition, a detailed analysis of the effects of the eight metals on all life stages (and therefore, susceptibilities) of test organisms has not been done. Toxicity data considered here are those from EPA Criteria Documents; in many instances, these data include the results of toxicity tests with life stages other than adults.

All organisms that occurred in Chesapeake Bay were assigned to the low ($<$10 ppt) salinity site, the high ($\geq$10 ppt) salinity site, or both (Lippson 1973, Wass et al. 1972).

Next, by using the recalculation procedure detailed by U.S. EPA (1982b), site-specific acute water quality criteria were calculated for each metal for (a) Chesapeake Bay, disregarding the organisms' preferred salinity; (b) Chesapeake Bay, low salinity; and (c) Chesapeake Bay, high salinity. The results, along with comparable national criteria, are shown in Table 9.

COMPARISON OF NATIONAL AND SITE-SPECIFIC CRITERIA

Based on the recalculation procedure, there is little difference between the national water quality criteria for eight metals and saltwater organisms and the site-specific criteria for the same metals and organisms indigenous to Chesapeake Bay (Table 9).

The criteria for five of the eight metals at the low-salinity site are numerically lower than both the national criteria and the criteria for the high-salinity site. However, the differences are slight, usually less than a factor of two. With the exception of Cd, there are almost no differences between the national criteria and the criteria calculated for the high-salinity site.

TABLE 9. NUMERICAL ACUTE WATER QUALITY CRITERIA FOR SALT-WATER ORGANISMS (MICROGRAMS PER LITER; PARTS PER BILLION)

Metal	National Criterion	Chesapeake Bay Criterion Overall	Low Salinity	High Salinity
Arsenic	242.3	240.5	138.7	240.5
Cadmium	55.2	96.0	39.4	96.0
Chromium	2,343	2,681	2,656	2,612
Copper	6.78	4.74	11.95	4.74
Lead	434.3	391.8	234.5	391.8
Mercury	3.848	4.323	2.188	4.224
Nickel	201.[a]	192	391	192
	137,[b]	201	391	201
Zinc	174.[a]	170	78	170
	173[b]	174	68	174

[a] Based on toxicity data for "Family Mean Acute Values."

[b] Based on toxicity data for "Species Mean Acute Values."

For all of the eight metals except one, three of the four most sensitive families used to calculate the national criteria are indigenous to Chesapeake Bay. Thus, the similarity between the site-specific and the national criteria is the result of similar data being used in the recalculation procedure. Where dissimilarities occur, they are caused by using a lower total number of families and by the exclusion of sensitive species not present in Chesapeake Bay.

Based on extant data and current national guidelines, it appears that a water quality criterion derived for a metal in salt water can be applied to most estuarine or marine waters.

This supports the hypothesis that if a metal is biologically available to an aquatic organism of a particular physiological make-up, the effect of the toxicant will be the same whether the organism is indigenous to Puget Sound, the Gulf of Mexico, or Chesapeake Bay. That is, if a family of animals that has a wide distribution and contains species sensitive to a toxicant is represented at a site, then the effect of the toxicant will likely be the same at a variety of sites. If such a relationship exists for other kinds of chemicals and other specific salt water bodies (and it appears that it does, based on work with organisms from Narragansett Bay, Rhode Island, and Escambia Bay, Florida),[7] the derivation of site-specific water quality criteria by the recalculation procedure may be less appropriate than deriving the national criteria using all available data over the range of species sensitivity.

CONCLUSION

To develop more meaningful and accurate site-specific water quality criteria, it will be necessary to use the more expensive, time-consuming procedures allowed by EPA where toxicity tests are conducted with resident species and site water. Such tests will assure that the test organisms are the same as or closely representative of those animals of local interest, and that the effects of water quality on the action and availability of the toxicant are taken into account.

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[7] Personal communication: "Relative Sensitivity of Indigenous Species to Toxicants," J. Gentile, U.S. EPA, Narragansett, D. Hansen, U.S. EPA, Gulf Breeze, 1983.

SECTION 5
TRENDS IN DISSOLVED OXYGEN

Dissolved oxygen is of primary interest to water quality managers, because it directly affects the well-being of aquatic life. Sources of oxygen include diffusion through the surface from the atmosphere, photosynthesis, and reduction of oxidized chemical species. Oxygen is lost from the water through respiration and oxidation of reduced chemical species.

The oxygen concentration of estuarine water is influenced by the physical, biological, and chemical characteristics of the estuary. The saturation concentration for DO decreases with increasing salinity (about -0.05 mg L^{-1} ppt^{-1}) and increasing temperature (about -0.2 mg L^{-1} $^{o}C^{-1}$). So temporal and spatial changes of DO concentrations would occur in an estuary devoid of organic material as the salinity and temperature of the system passed through annual cycles.

Organic material introduced into the system can serve as a source of additional oxygen or as a sink for oxygen. Photosynthesizing phytoplankton and submerged aquatic plants produce oxygen during daylight. All heterotrophic organisms consume oxygen, as do the plants at night, and thus, become a sink for it. Biological oxygen consumption occurs both in the water column and in the sediments. Some chemical reactions, occurring primarily in sediments, also consume oxygen. The oxygen concentrations measured in estuaries are the net result of these interacting factors.

A distinct annual cycle in DO concentrations exists in Chesapeake Bay. Low temperatures and high mixing rates in winter maintain near-saturation concentrations at all depths in the estuary. In spring, freshwater input from the Susquehanna River reduces the mixing rate by increasing density stratification in the Bay, and warmer temperatures reduce oxygen solubility in the water. The warmer temperatures may also stimulate organism respiration. As a result of these factors, the oxygen concentration declines and may reach zero when consumption processes operate faster than production and reaeration processes. Regions of Chesapeake Bay deeper than about 10 m have experienced low oxygen concentrations in summer for as far in the past as data were taken. Cooling temperatures and increased wind mixing begin reaerating the deep water in fall to complete the annual cycle.

Because the DO cycle is a major annual feature in Chesapeake Bay with significant water quality implications, it has been examined with as much detail as the 1950 to 1980 data allow. The data considered here were all collected by investigators from the Chesapeake Bay Institute with Winkler titration methodology. These data were selected because of fairly uniform precision and accuracy over time, especially at low DO concentrations. Oxygen electrode measurements were excluded from this analysis because of uncertainty in electrode response at low concentrations and under reducing conditions.

The first step in the analysis was to estimate the volume of water subjected to low DO concentrations for eleven years between 1950 and 1980. For purposes of this analysis, "low" is defined as 0.5 ml L^{-1} (0.7 mg L^{-1}) or less. At typical summer salinity and temperatures, 0.5 ml L^{-1} represents approximately 10 percent of saturation. The data are presented in Figure 13. The trend is toward a greater volume of water with low DO concentrations. Comparing the two ends of the graph, the volume in July 1980 was about 15 times the volume in July 1950.

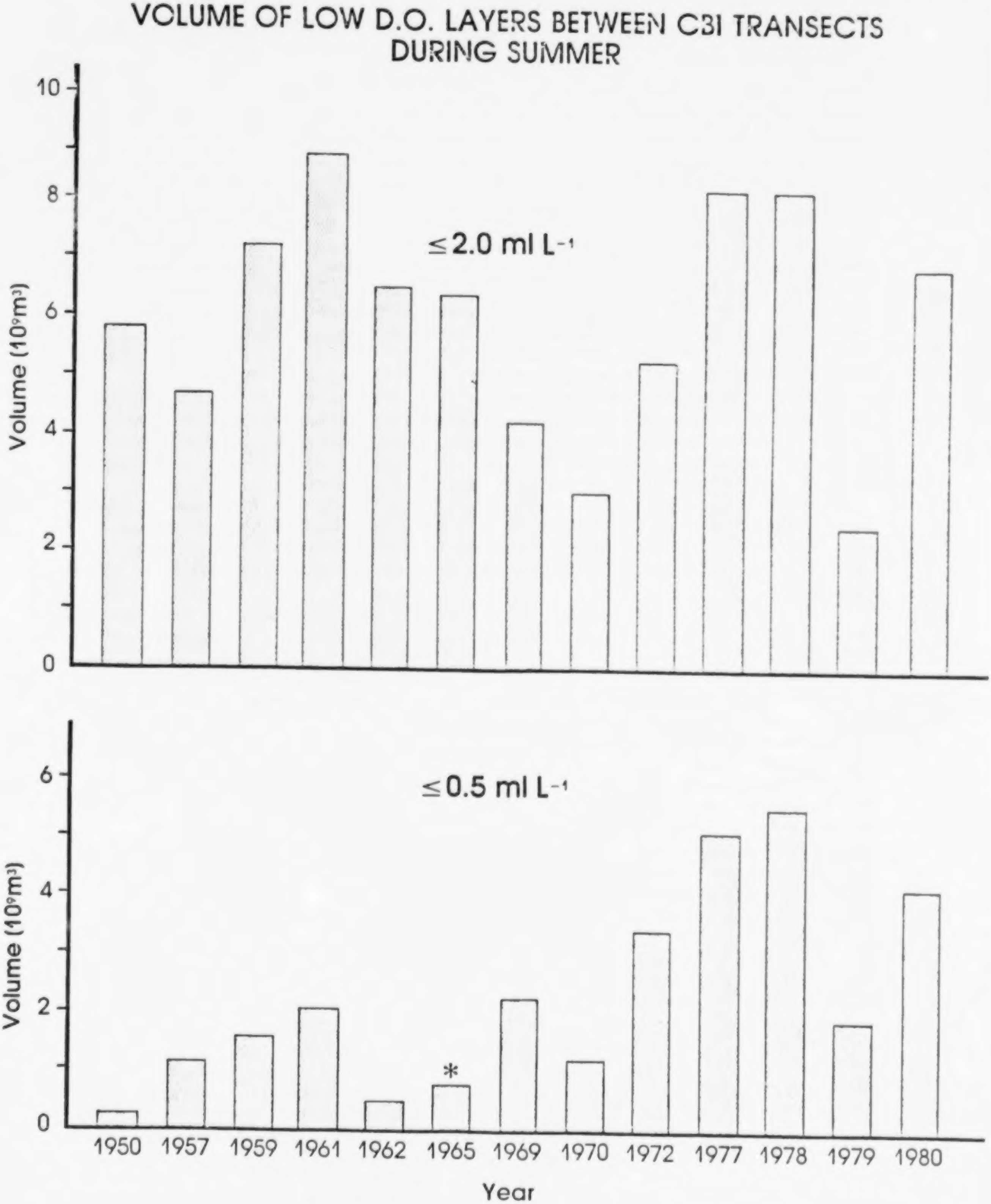


Figure 13. Volume of water with summer DO 0.5 ml L^{-1} and 2.0 ml L^{-1}

The total volume of water that could become anoxic should be defined by the bottom topography and halocline depth. For the main portion of Chesapeake Bay, the potential region for anoxia extends from the channel of the Patapsco River south to about Reedville, Virginia, near $37^{o}45'$N latitude. In this region the halocline is usually between 8 m and 14 m deep. In July 1980 nearly all of the potential volume contained low DO water, most of it anoxic. In 1977 and 1978, the low oxygen water was present above the edge of the topographic depression.

The second step in the analysis was to determine spring flows for each of the years from 1950 to 1980. This is important in terms of both the effect on stratification in the Bay and the delivery of material that contributes to the oxygen demand of the system. Monthly average stream flow of the Susquehanna River at Harrisburg for March, April, and May were summed for each year. The 31-year mean was formed, and the deviation from the mean calculated for the spring of each year. Figure 14 illustrates deviation from mean spring flow. The Harrisburg data were used rather than those from Conowingo Dam because the Conowingo data were available only back to 1968. The flow at Conowingo is about 10,000 to 20,000 cfs higher than at Harrisburg with no discernible lag time in peak flows.

Third, the years for which oxygen data exist were identified and are indicated by large open circles in Figure 14. Because 1950 and 1980 had comparable spring flows and oxygen data, they were selected for more detailed comparison. Spring flow for 1957 was close to that for 1950 and 1980 so its oxygen data were also considered as necessary.

Fourth, the annual flow records for 1950, 1957, and 1980 were graphed and appear in Figure 15 along with the 1980 flow at Conowingo. It was hypothesized that these three years would exhibit similar stratification patterns, so differences in DO concentrations could be attributed to other factors.

Next, review of the oxygen data revealed that many of the same stations were visited in May 1950 and 1980, July 1950 and 1980, and September 1957 and 1980. These stations shown in Figure 16 were selected for comparison.

Because salinity has the major influence on water density in the estuary, it is used here as an indicator of stratification. Though temperature also affects density, its influence is small with respect to salinity. Figure 17 shows comparisons between salinity and DO profiles for the periods cited above. At station 848E on May 22, 1950, the salinity stratification was slightly greater than on May 21, 1980 (Figure 17a), but the DO change was less (Figure 17b) in 1950 than 1980. The temperature at 19 m was 10.9 ^{o}C in 1950 as opposed to 13.5 ^{o}C in 1980. On July 18, 1950 (Figure 17c), the salinity was generally less than on July 28, 1980, and the surface to bottom difference was 7.4 ppt in 1950 versus 5.8 ppt in 1980. Temperatures were 21 ^{o}C at 18 m in 1950 and 24.2 ^{o}C at 18 m in 1980. In both years DO decreased with depth (Figure 17d) with minima of 0.13 mg L^{-1} in 1950 at 34 m and 0 mg L^{-1} at 16 m in 1980. On September 11, 1957, the salinity was similar to September 29, 1980 (Figure 17e), with surface to bottom salinity changes of 5.9 ppt and 6.4 ppt respectively. Temperatures at 18 m were 23.9 ^{o}C and 24.5 ^{o}C, respectively. Dissolved oxygen was generally lower in 1980 than in 1957. The minima were 0.59 mg L^{-1} at 23 m in 1957, and 0 mg L^{-1} at 16 m in 1980.

Two stations farther downstream (818P and 804C) were likewise examined. On May 24, 1950 at station 818 (Figure 18a), the salinity was similar to that of May 21, 1980. Surface to bottom differences were 8.3 ppt and 7.2 ppt, respectively. Temperatures at 18 m were 12.3 ^{o}C and 14.6 ^{o}C, respectively. Dissolved oxygen was generally lower (Figure 18b)

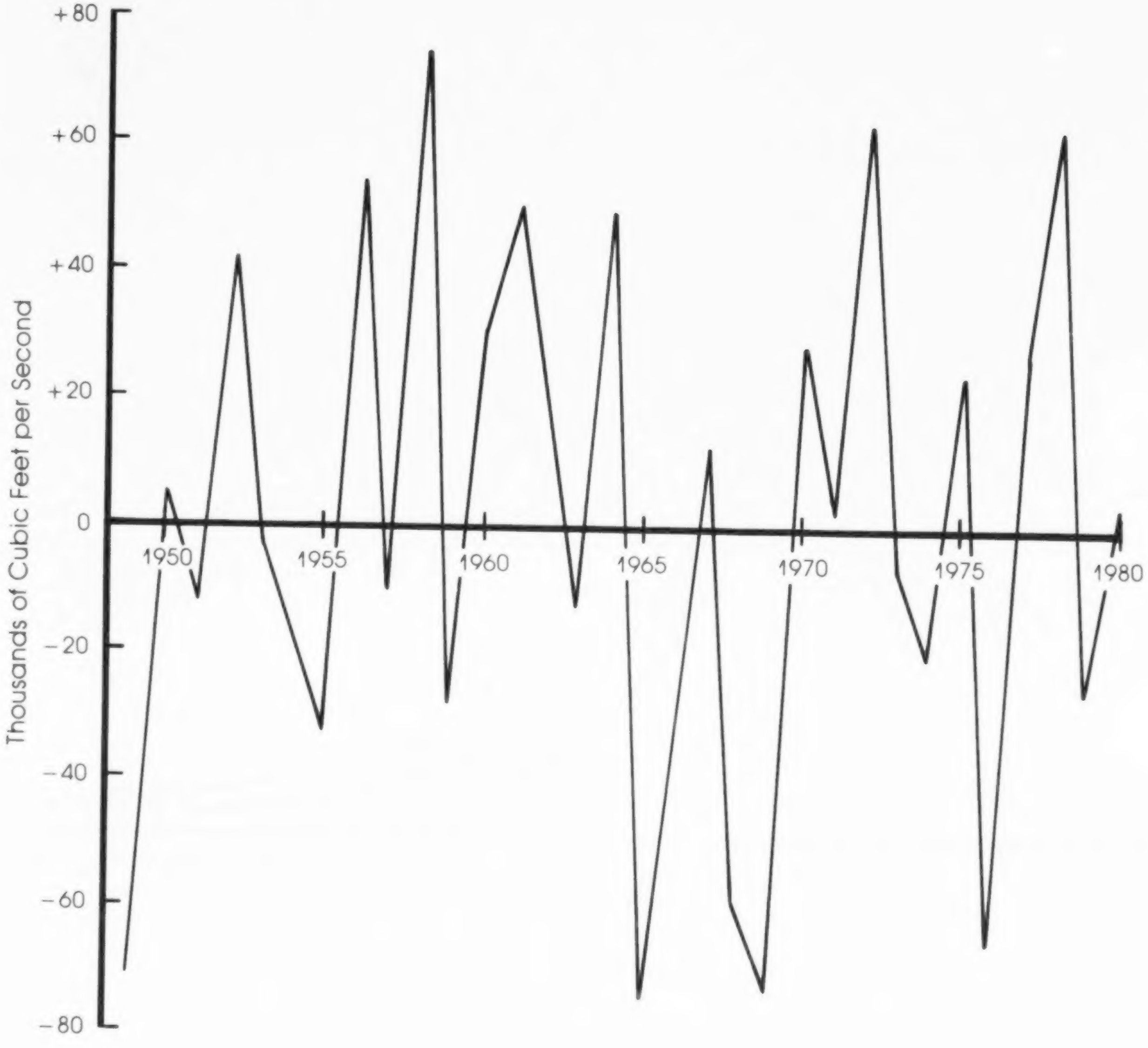


Figure 14. Susquehanna River spring flow, deviation from 31 year mean.

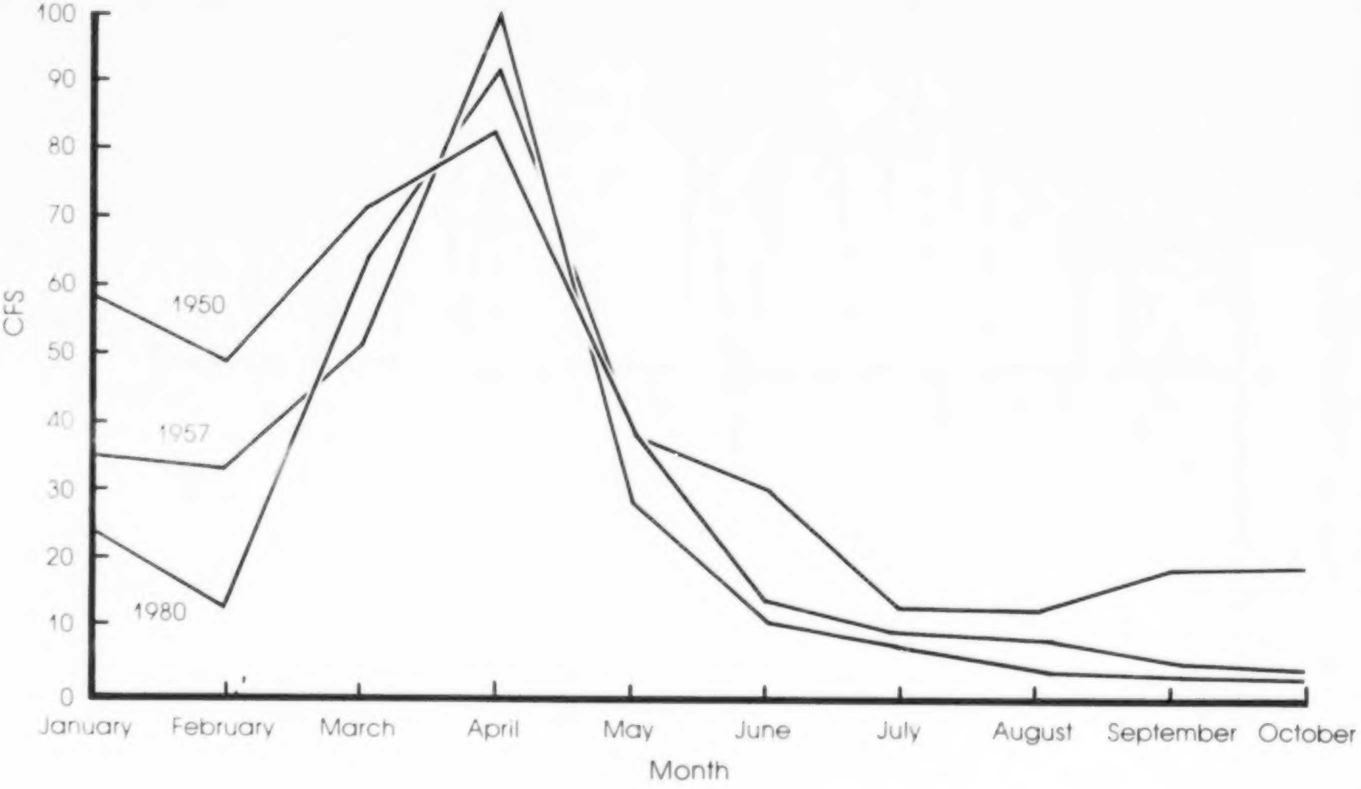


Figure 15. Monthly mean river flow of Harrisburg at Conowingo

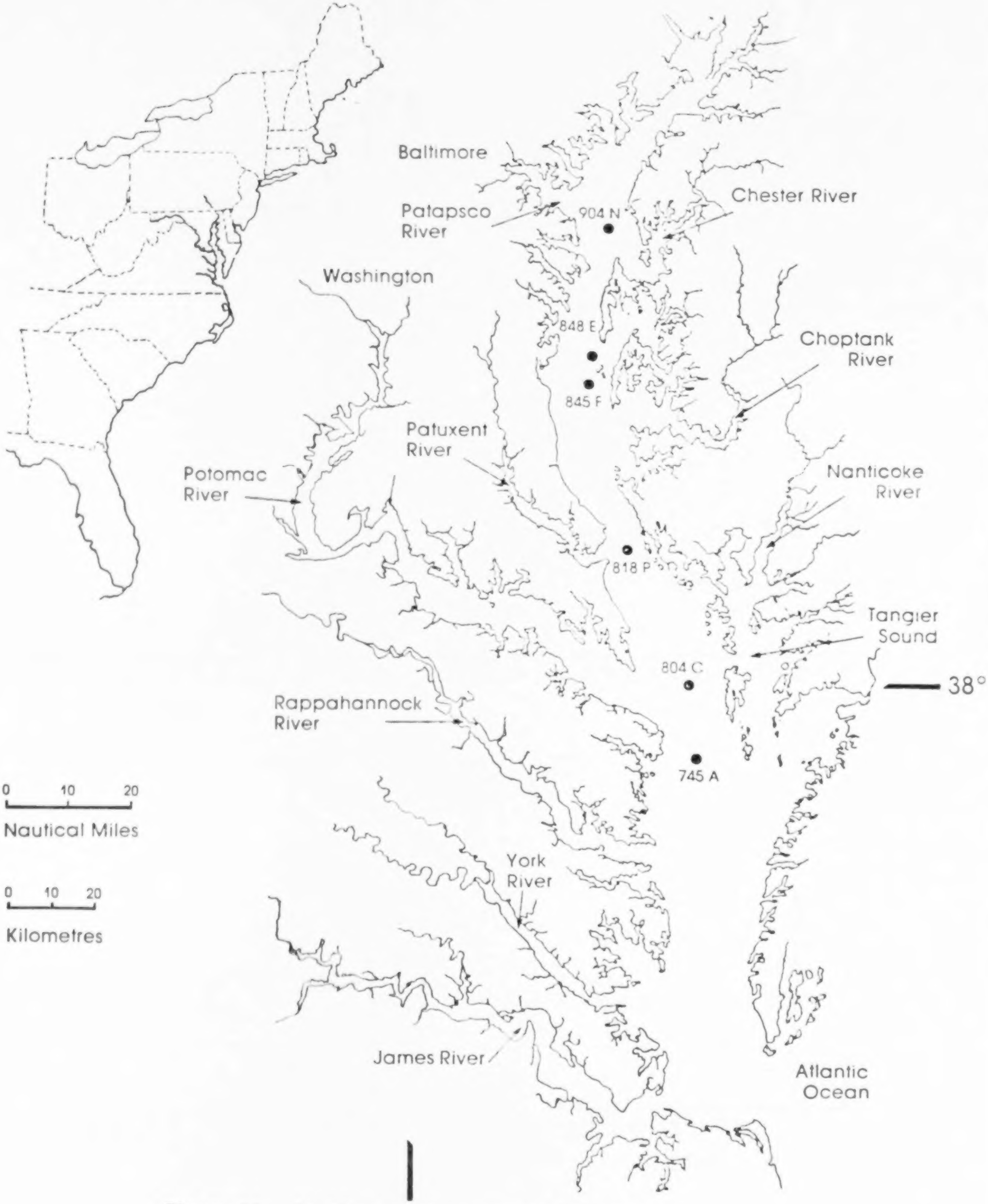

Baltimore
Patapsco River
904 N
Chester River
Washington
848 E
845 F
Choptank River
Patuxent River
Potomac River
Nanticoke River
818 P
Tangier Sound
804 C
38°
Rappahannock River
745 A
0 10 20
Nautical Miles
0 10 20
Kilometres
York River
James River
Atlantic Ocean
77°

Figure 16. Stations used to sample for oxygen.

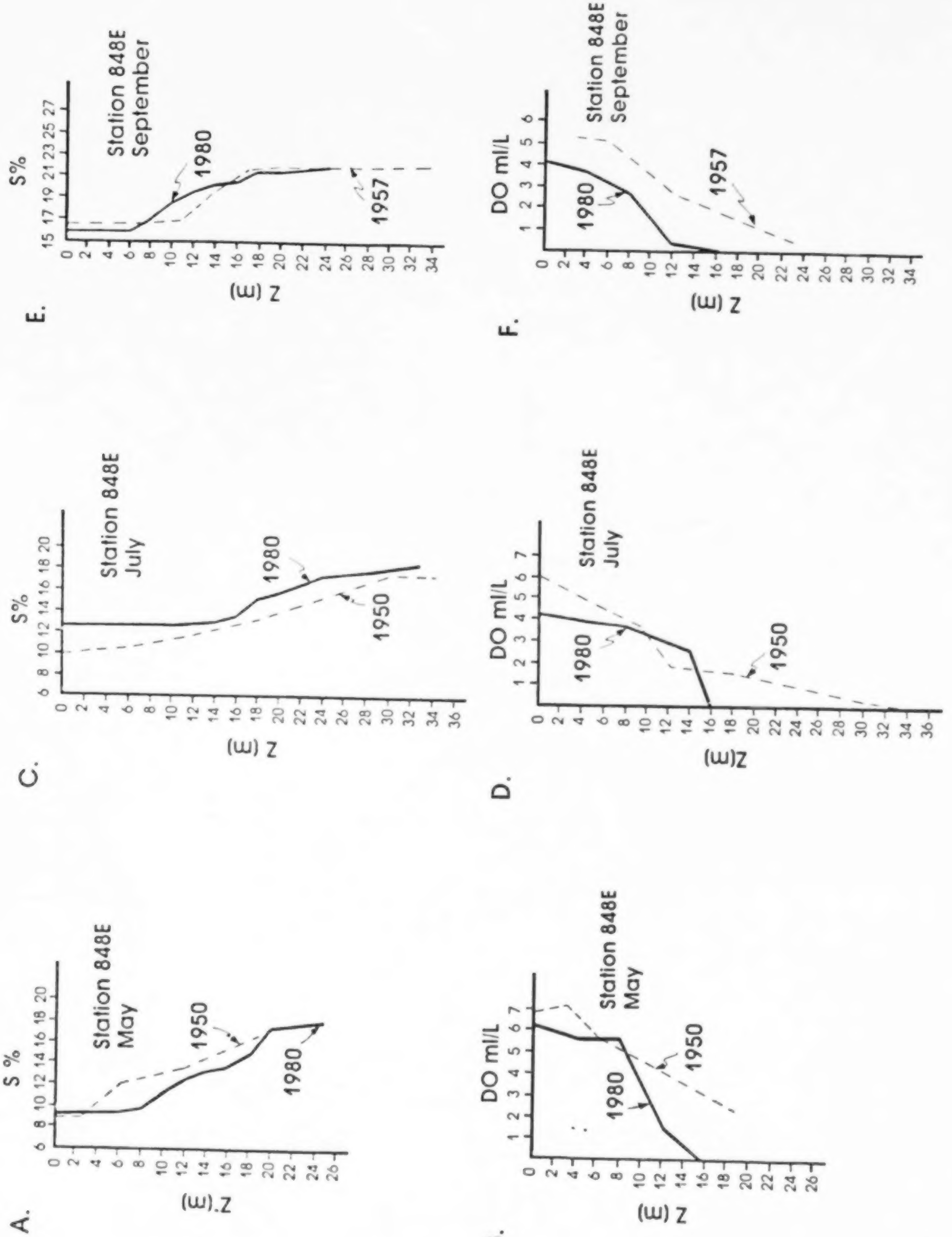


Figure 17. Comparisons between salinity and DO profiles.

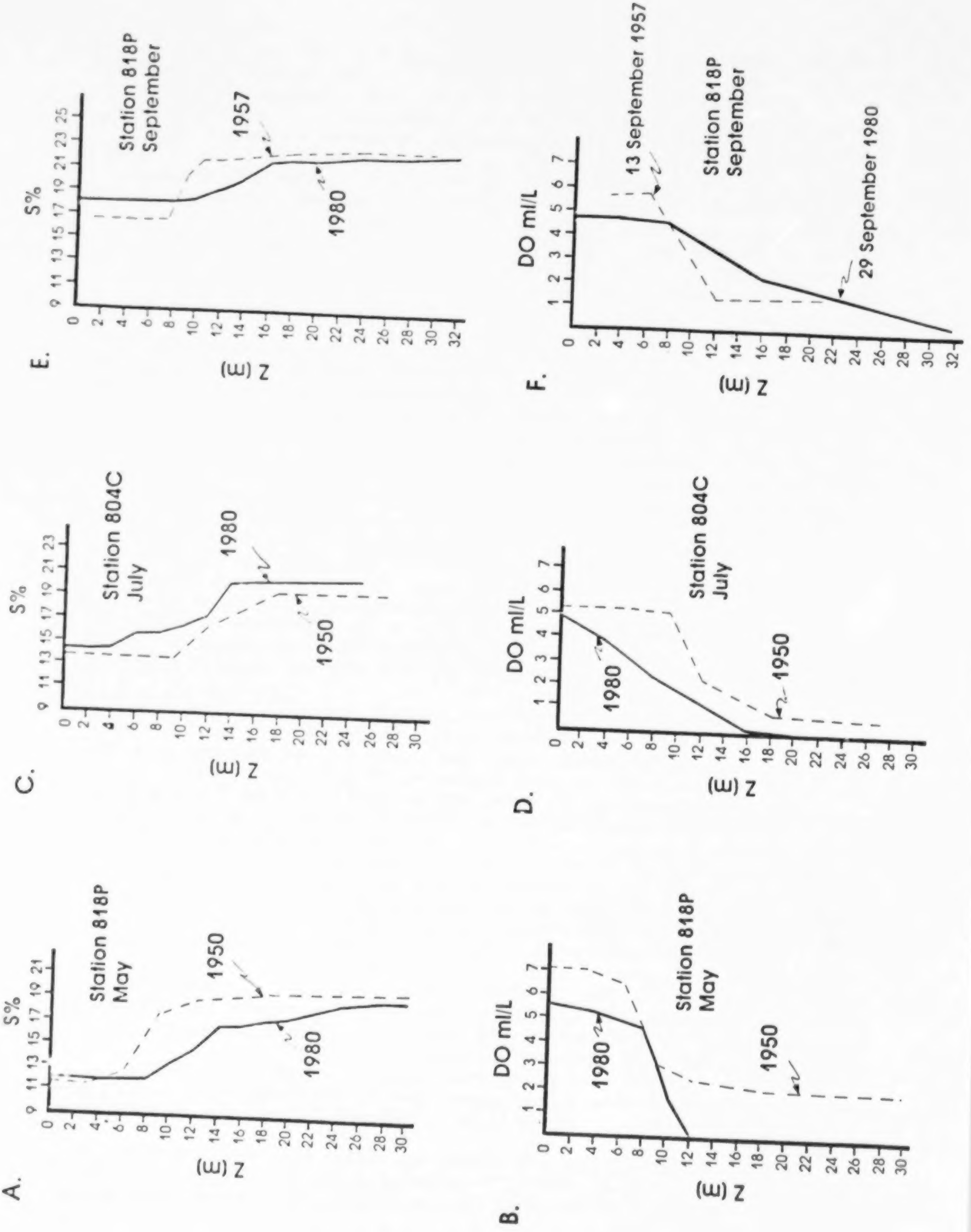


Figure 18. Comparisons between salinity and DO profiles.

in 1980. Minima of 2.1 mg L^{-1} occurred at 30 m in 1950 and 0 mg L^{-1} at 10 m in 1980. On July 17, 1950 (Figure 18c), the salinity gradient at station 804C was similar to that on July 31, 1980. Surface to bottom differences were 6.21 ppt and 6.61 ppt, respectively with temperatures at 18 m of 23.0 °C and 25.2 °C, respectively. Dissolved oxygen was less at all depths in 1980 (Figure 18d), with minima of 0.57 mg L^{-1} at 27 m in 1950 and 0 mg L^{-1} at 24 m in 1980. Salinities at station 818P (Figure 18e) were somewhat different in September 1957, and 1980; greater salinity stratification existed on September 13, 1957, with a surface to bottom difference of 6.26 ppt as opposed to 4.51 ppt for September 30, 1980. Temperatures at 18 m were 23.7 °C in 1957 and 24.3 °C in 1980. The DO gradient was steeper in 1957 than in 1980 (Figure 18f), but measurements were not made to the bottom. Minimum values were 1.47 mg L^{-1} at 21 m in 1957 and 0.31 mg L^{-1} at 32 m in 1980.

The salinity graphs in Figures 17 and 18 generally are comparable for the stations and years selected. This tends to confirm the hypothesis that the years 1950, 1957, and 1980 have similar stratification patterns as well as similar Susquehanna River flows. Dissolved oxygen concentrations, below the halocline, were generally lower at all stations in 1980 than in the previous years. Temperatures in 1980 were also slightly warmer, which would reduce saturation concentrations, but do not account for the lower concentrations that were well under-saturated.

To view the data from another perspective, the volume of water subject to low DO concentrations can be estimated for July and August in eleven years between 1950 and 1980. For purposes of this analysis, "low" is defined as 0.5 ml L^{-1} (0.7 mg L^{-1}) or less. At typical summer salinity and temperatures, 0.5 ml L^{-1} represents approximately 10 percent of saturation. The data are presented in Figure 18. The trend is toward a greater volume of water with low DO concentrations. Comparison of the two ends of the graph show that the volume in July 1980 was about 15 times the volume in July 1950.

The total volume of water that could become anoxic should be defined by the bottom topography and halocline depth. For the main portion of Chesapeake Bay, the potential region for anoxia extends from the channel of the Patapsco River south to about Reedville, Virginia, near 37°45'N latitude. In this region, the halocline is usually between 8 m and 14 m deep. In July 1980 nearly all of the potential volume contained low DO water, most of it anoxic. In 1977 and 1978, the low oxygen water was present above the edge of the topographic depression.

Although low DO concentrations are a normal feature of the annual cycle, oxygen was detectable at all depths in 1950 and 1957. Conversely, oxygen was frequently absent from deep water in May, July, and September 1980. One could hypothesize that the anoxic conditions observed in 1980 resulted from the oxygen demand caused by greater organic material concentrations in 1980 than in 1950 or 1957. Unfortunately, there are insufficient data on total nutrients, chlorophyll *a*, or other indicators of organic content for 1950 and 1957 to test the hypothesis directly. However, some indirect tests are possible.

The first indirect test of the hypothesis is provided by graphing the change in salinity across the halocline against the change in DO across the same depth interval for stations between 904N and 804C in May 1950 and 1980 (Figure 19).

The six data points for 1950 gave a regression line -- DO = 0.52, S ppt + 0.22 with r = 0.93. The data, except for station 904N, for May 1980 fall well off the regression line. For an incremental salinity increase of

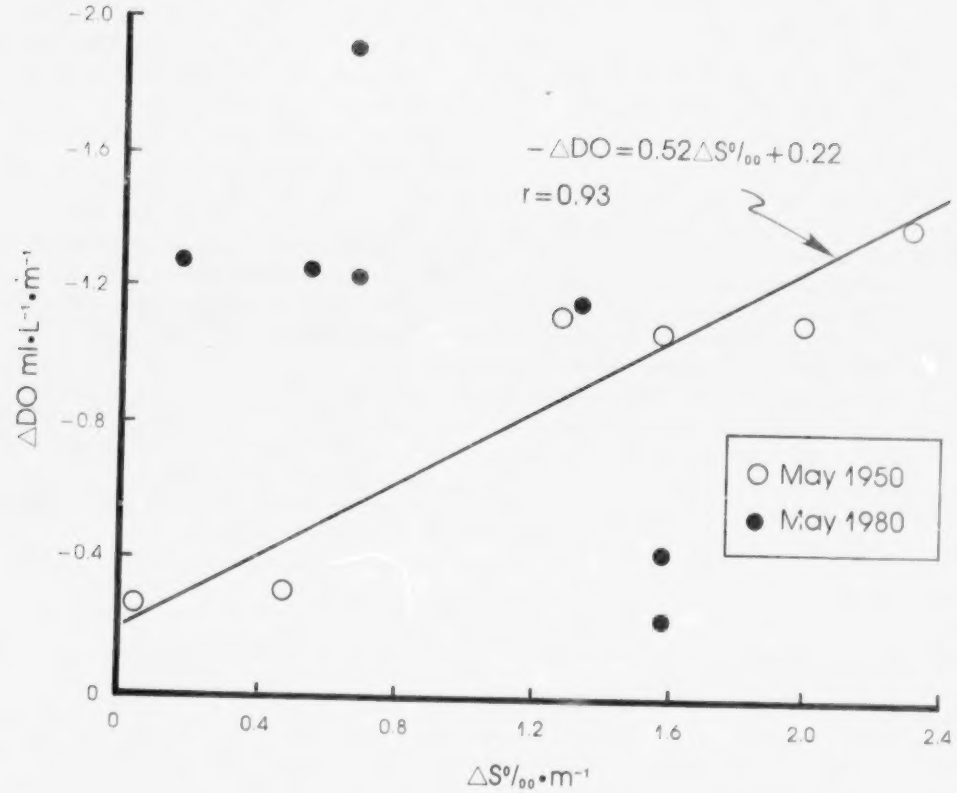


Figure 19. Relation between salinity increase and dissolved oxygen decrease in two springs with similar flows.

about 0.4 ppt m^{-1}, the DO decrease in May 1980 is about five times the decrease in May 1950 and is independent of salinity stratification. This suggests a greater demand for oxygen below the halocline in May 1980, perhaps because of increased organic content of the deep water.

A similar graph was developed for all available data taken at stations 848E and 845F during July, 1949, 1950, 1957, 1959, 1961, 1962, 1969, 1970, 1977, 1979, and 1980 (Figure 20). These data gave a regression line -- DO = 0.55, S ppt + 0.22 with r = 0.87, which is nearly identical to the line developed with the May 1950 data. This similarity indicates that, regardless of spring flows, by July the relative change in DO across the halocline is primarily a function of the salinity control on stratification. However, the absolute concentration of DO below the halocline is a function of both the stratification effect and the DO concentration above the halocline. The data in Figure 21a-f indicate that oxygen concentrations approach but do not reach zero when near surface concentrations are greater than about 5 ml L^{-1}. In the two other years illustrated (Figure 21g, h), near surface values are less than 5 ml L^{-1}, and anoxia was observed below the halocline.

There could be several explanations for these observations. First, the time of day of the measurements was not uniform. The oxygen concentration in the upper layer should increase during daylight because of phytoplankton photosynthesis and decrease at night from respiratory processes. Second, the organic content of the upper layer could be greater in 1977 and 1980, exerting a proportionally larger oxygen demand. Third, meteorological events could have aerated the upper layer before measurements were taken in the years prior to 1977. Fourth, temperature could have influenced respiratory rates in different ways prior to 1977. Fifth, the dominant plankters could have been different, with different biomass specific metabolic activities, in earlier and later years.

These are interesting possibilities, but let us return to the hypothesis that anoxic conditions result from greater organic matter availability in recent years. The second indirect test of the hypothesis is provided by nitrogen and phosphorus concentrations in the fresh water entering the Bay from the Susquehanna River. The annual average nitrate (Figure 22) and total phosphorus (Figure 23) concentrations have approximately doubled since the mid-1960's. If these nutrients reached the region subject to summer anoxia, they could result in increased organic matter production and/or oxygen demand. In the region of the upper Bay from Susquehanna Flats to Pooles Island, total phosphorus, total nitrogen, and chlorophyll a annual average concentrations have also increased (Figure 24); Secchi depths have decreased (Figure 25) since the mid-1960's. Similarly, total phosphorus concentrations between Pooles Island and the Bay Bridge have increased (Figure 26). Total phosphorus concentrations have increased in the segment from the Bay Bridge to the Patuxent River (Figure 27). These nutrient trends do not directly confirm the hypothesis, but are consistent with it.

By inspection, it is possible to relate the observed nutrient concentration changes in the upper Bay to man's activities on the watershed. One index of activity is population changes. Figure 28 shows the population in the Susquehanna River drainage basin south of Sunbury, PA, the eastern shore, and the western shore of the upper Bay, including metropolitan Baltimore. The population increased by 40 percent between 1950 and 1980. However, the nutrient concentrations approximately doubled between the mid-1960's and 1980. This suggests that population increase alone does not account for all of the nutrient increase.

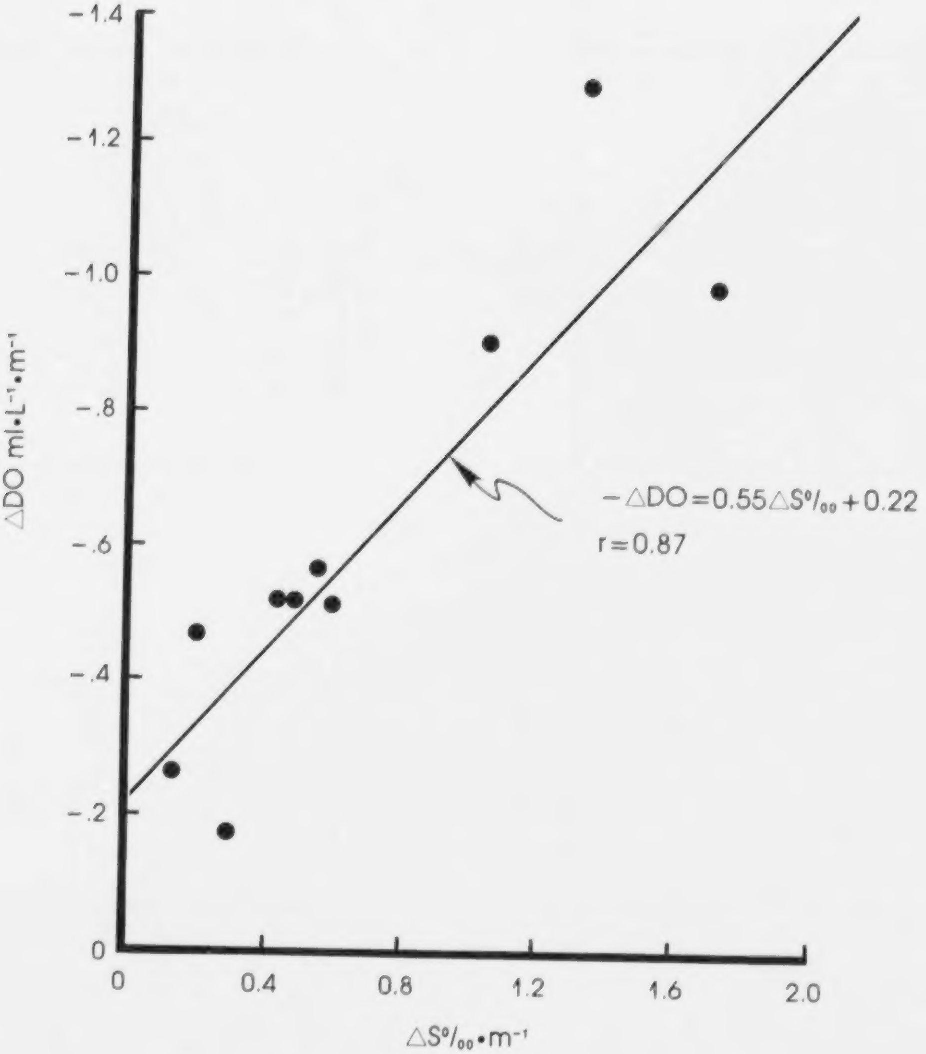


Figure 20. Oxygen decrease per unit salinity increase at stations 848E and 845F in July 1949 to 1980.

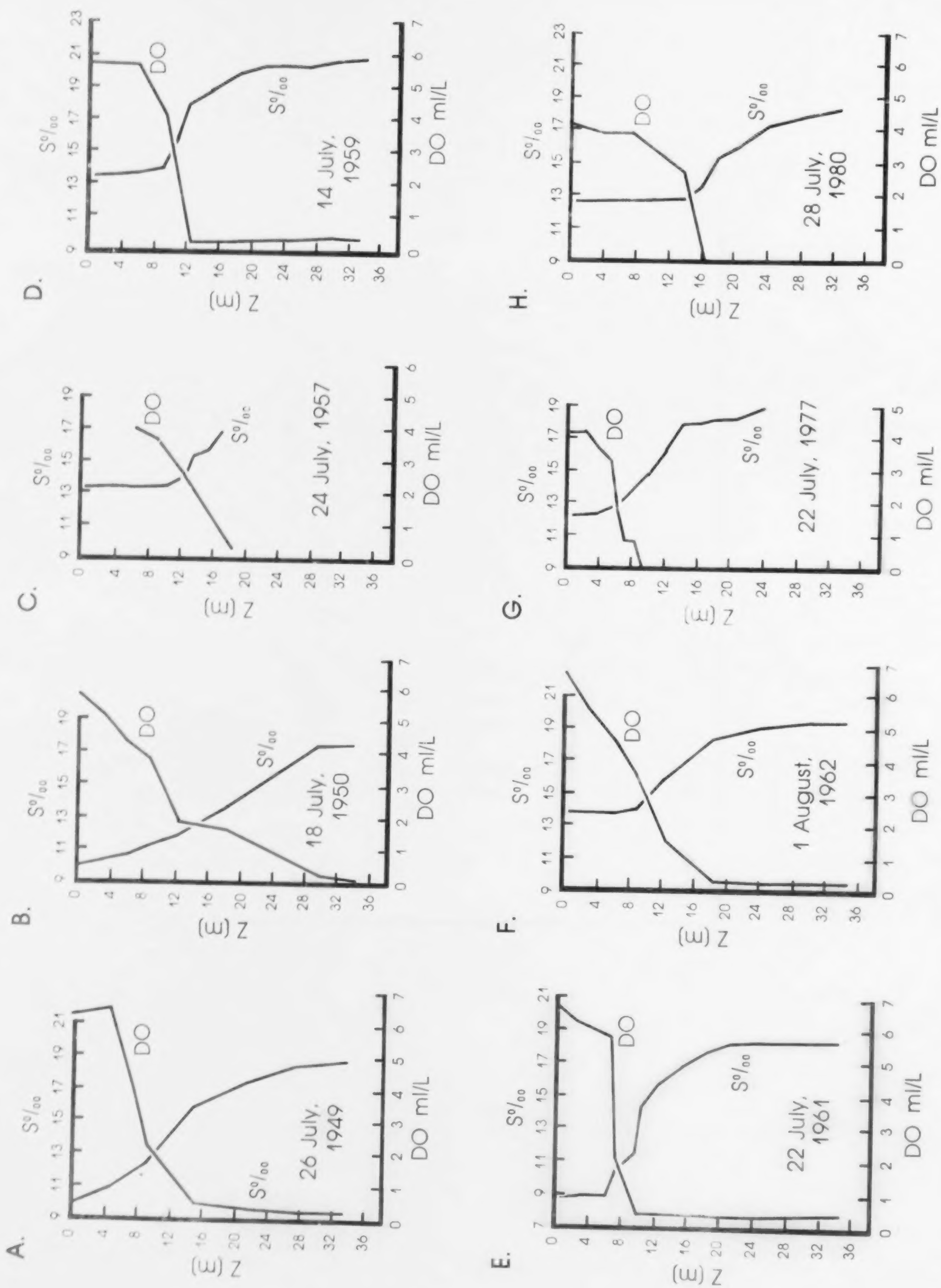


Figure 21. Concentration of DO across the halocline.

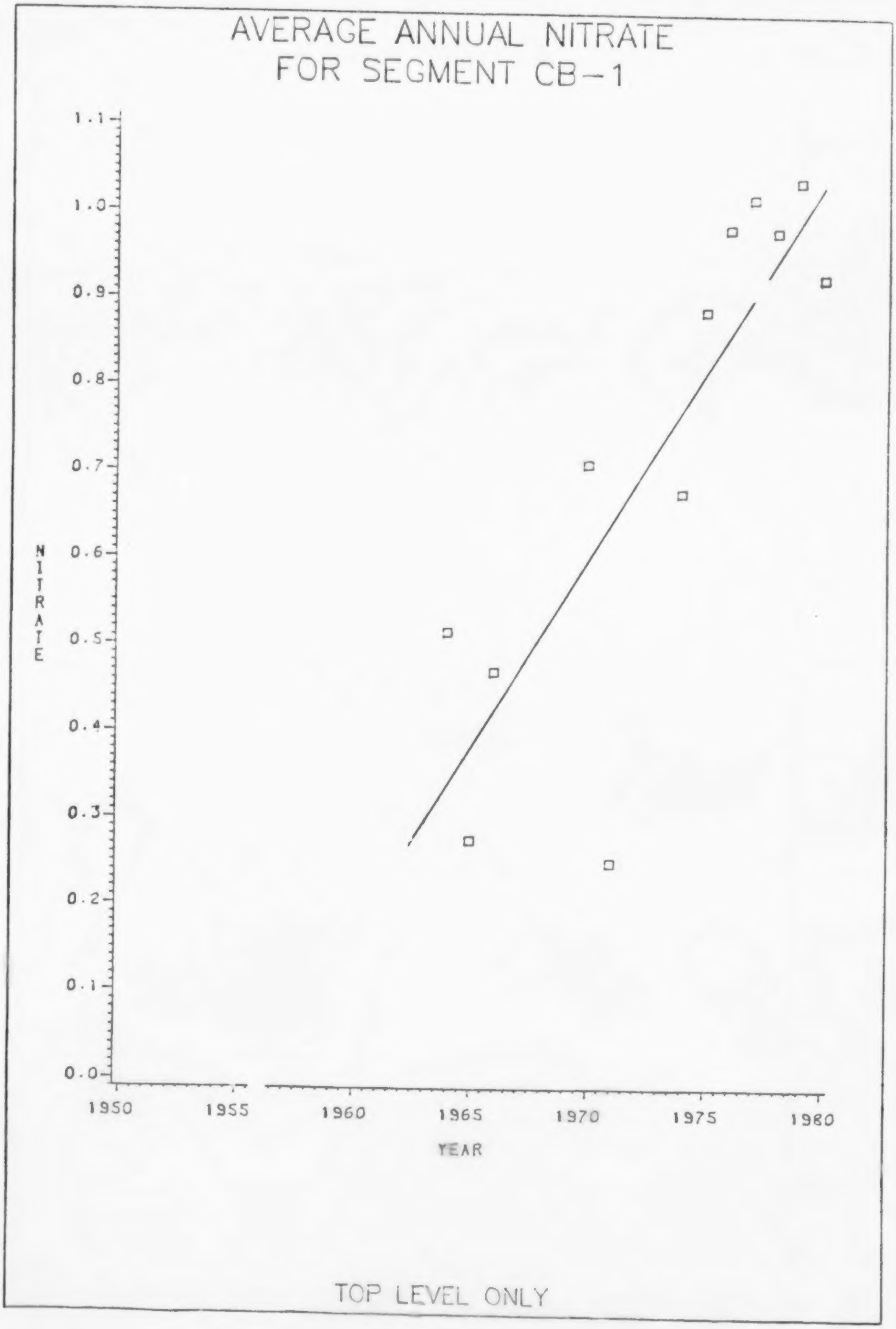


Figure 22. Average annual nitrate for segment CB-1.

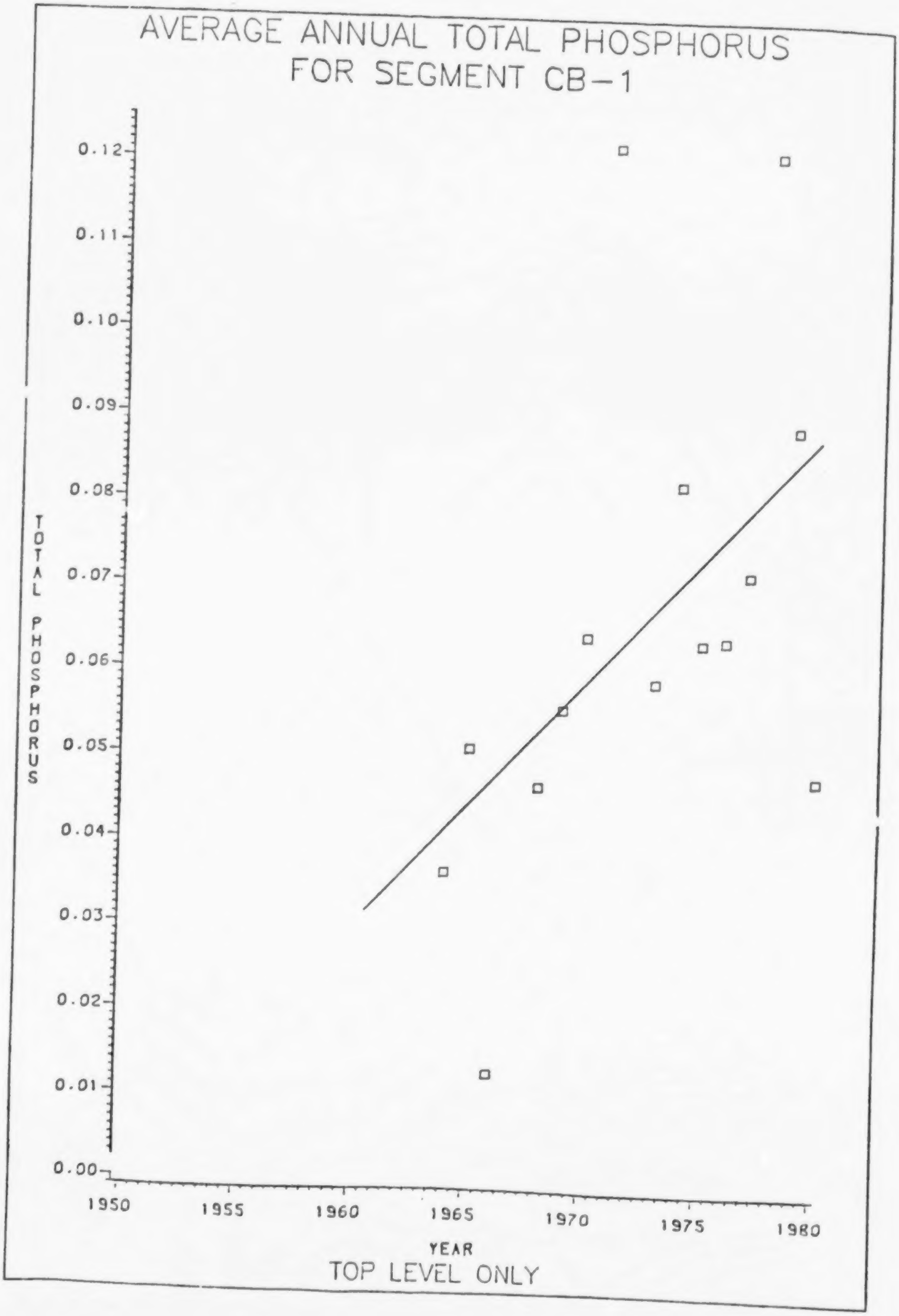


Figure 23. Average annual total phosphorus for segment CB-1.

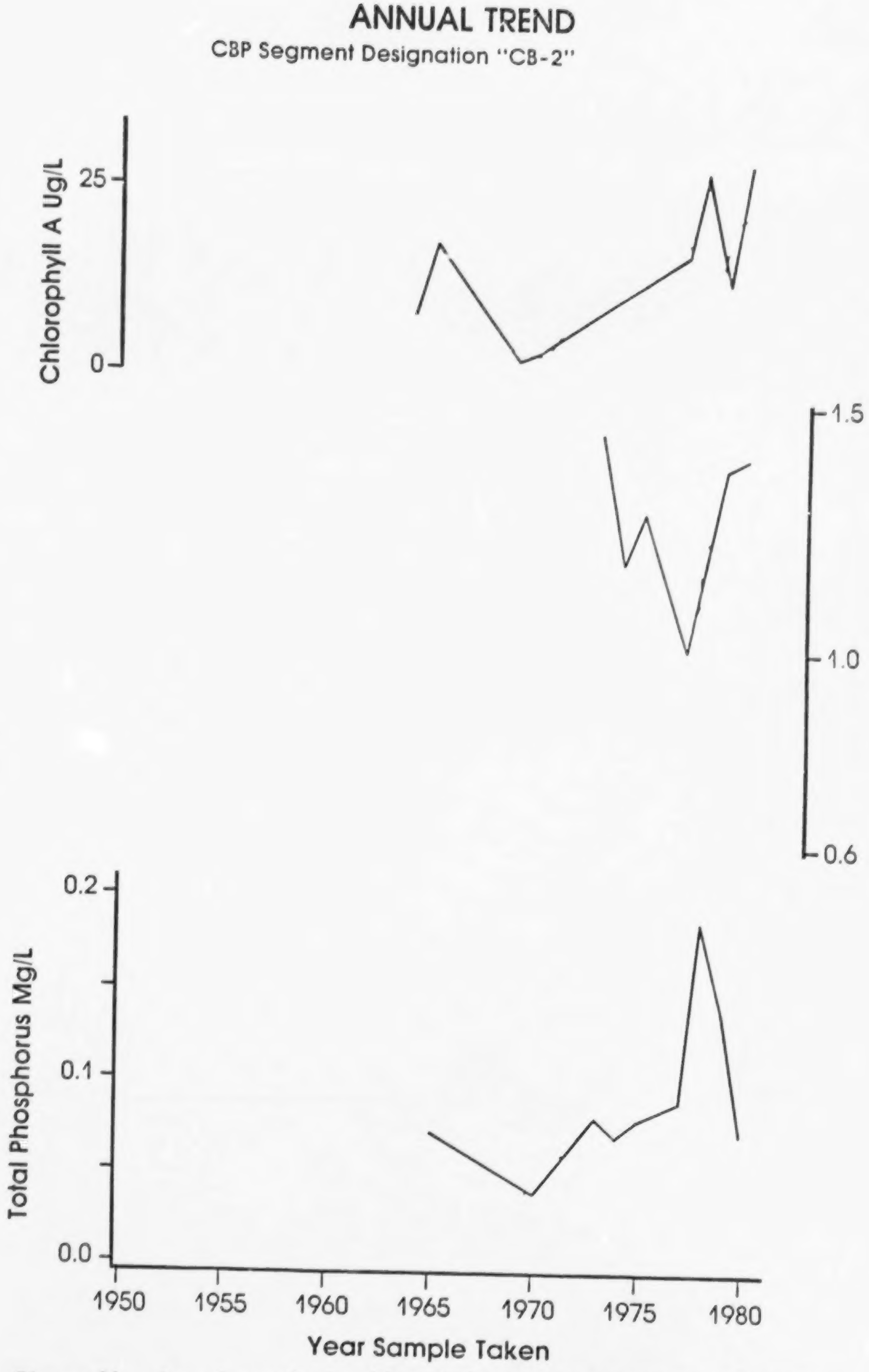


Figure 24. Annual trends in chlorophyll a, total nitrogen and total phosphorus in CB-2.

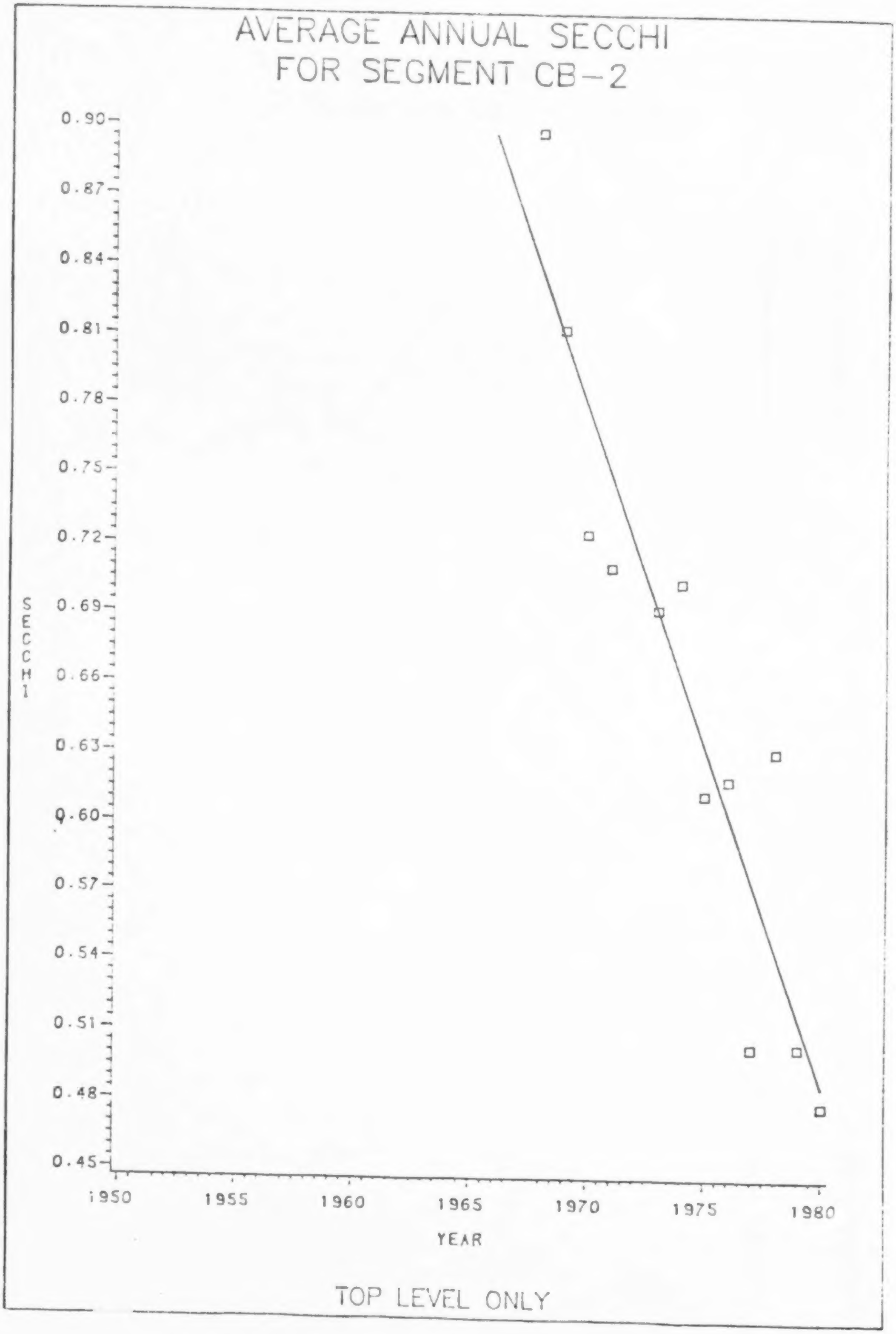


Figure 25. Average annual secchi for segment CB-2.

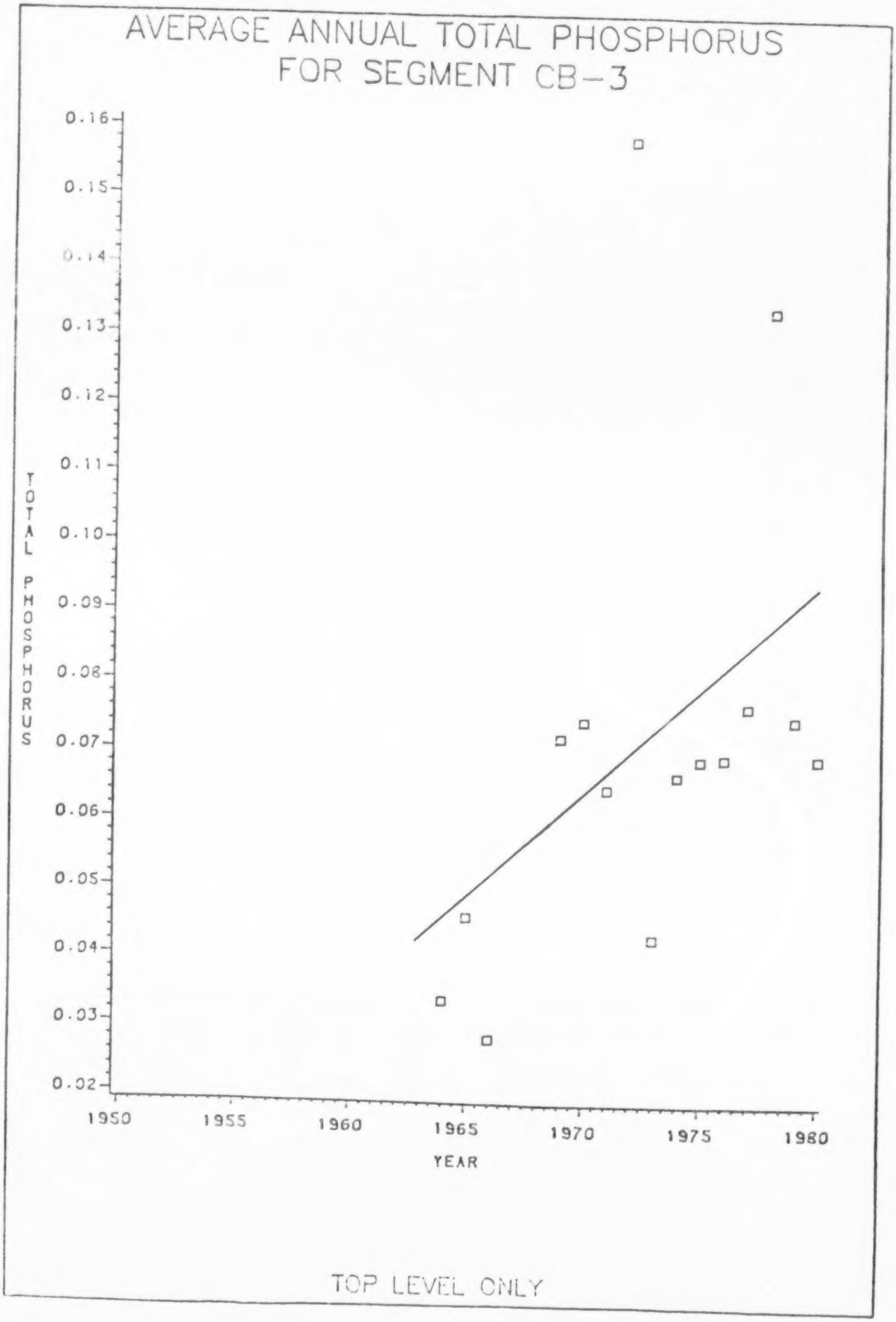


Figure 26. Average annual total phosphorus for segment CB-3.

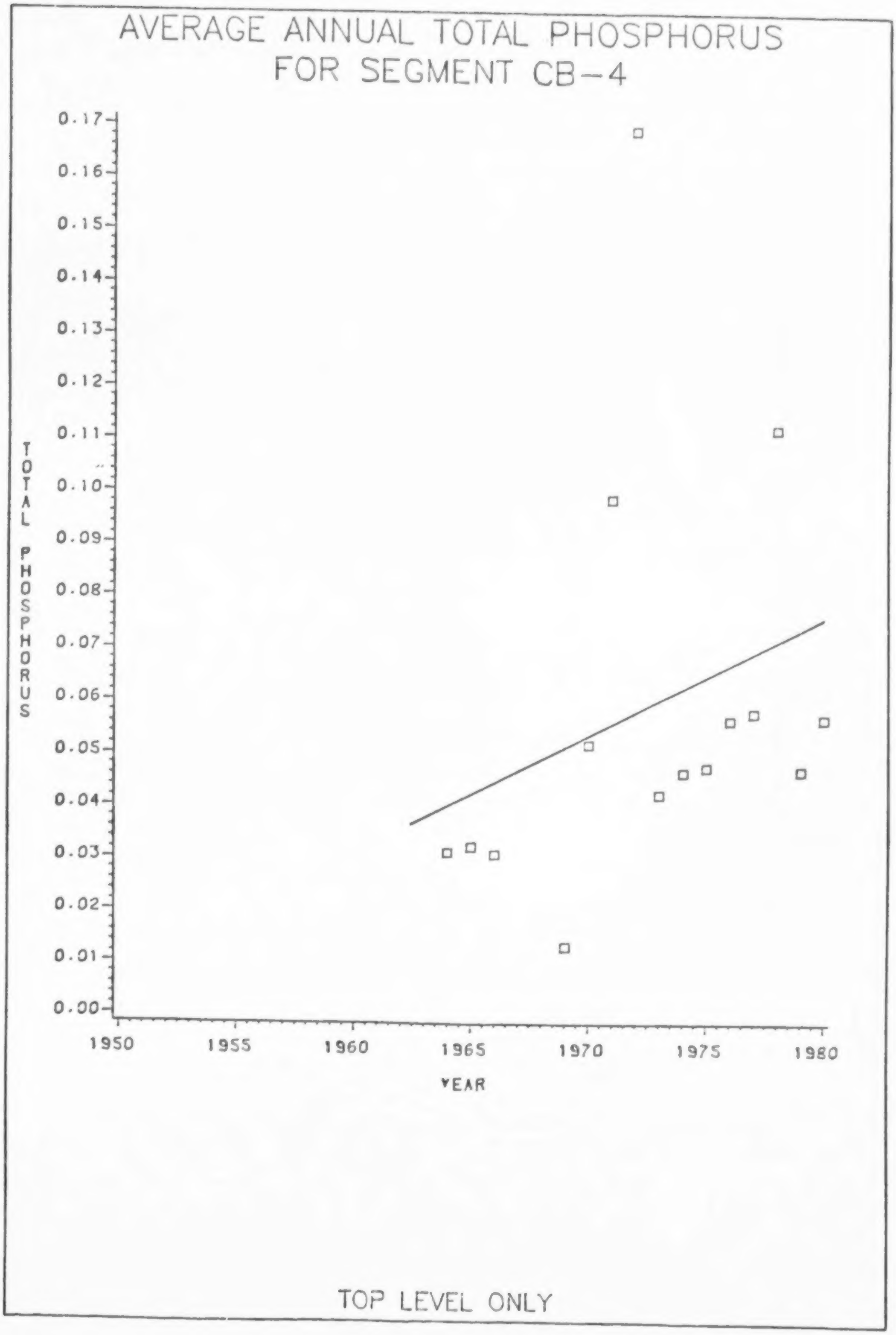


Figure 27. Average annual total phosphorus for segment CB-4.

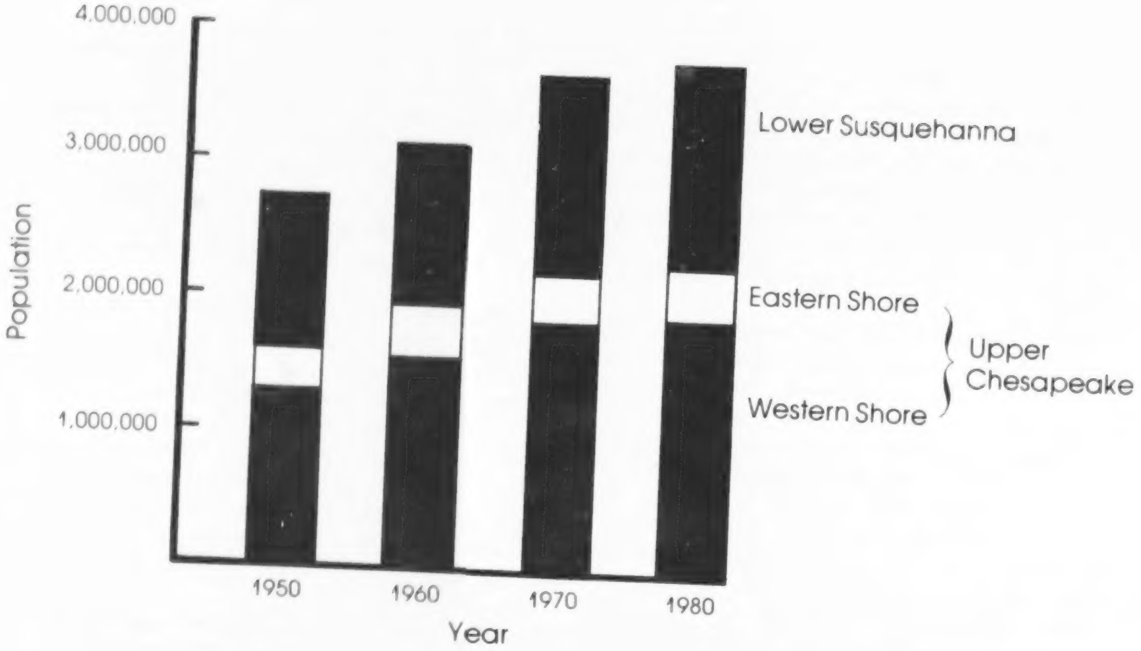


Figure 28. Population in upper Chesapeake - lower Susquehanna region.

A second consideration is the land-use patterns in the lower Susquehanna-upper Chesapeake region. Figure 29 shows that the amount of land in crops and pasture decreased, forest remained about the same, and other land uses increased. Uses in this category include urban areas, mines, quarries, marshes, and additional non-agricultural activities. The increase in other land uses since 1950 produces the same trend as the nutrient concentration changes, but it is not quite the magnitude of the nutrient changes.

Another aspect concerns increased production on existing agricultural land. At present the only data available at CBP is fertilizer consumption for the entire state of Pennsylvania. If we assume that agricultural practices are similar in the region under consideration, then the trend for fertilizer use in the lower Susquehanna and upper Chesapeake should be similar to the Pennsylvania data trend. Figure 30 shows that total nitrogen applied has doubled since 1955, and the application of nitrogen solutions increased by a factor of 135 in the same period. Total P_2O_5 consumption showed a decrease from 84,861 to 71,481 tons during the same period.

The patterns of man's activity on the watershed are consistent with the observed nutrient concentration changes in the upper Chesapeake Bay. Population has increased, and non-agricultural land use has similarly increased. Although the acreage used for agriculture and pasture has decreased, production has been sustained by increased fertilization and by growing three crops of some plants in two years rather than one crop per year. Because the use of nitrogen fertilizer has risen, the increased nitrogen concentrations in the upper Bay may be linked to agricultural activity. However, since phosphorus fertilizer use has decreased, the phosphorus increases in the Bay may be due to man's activity within the "other" land-use category.

There are two other aspects to the low DO situation in the main portion of the Bay: habitat loss and chemical alterations. When the Bay bottom is covered by low DO waters, aerobic benthic organisms lose their habitat, and demersal forms are excluded from the deeper portions of the water column. As the oxygen concentration approaches zero, phosphorus release from the sediments increases. The purpose of the following discussion is to estimate the changes in the affected sediment surface area as the oxycline depth changes.

Cronin and Mallonee's (1981) data on the dimensions of the Bay were utilized to compute the bottom area of the Bay for segments CB 1-5 as a function of depth. Note that segment CB-3 was subdivided into CB-3a (up-Bay from a line connecting Fort Howard and Swan Pt) and CB-3b (down-Bay from that line). That line represents the upstream penetration of low DO waters most of the time. The data are graphically summarized in Figures 31a and 31b. In Table 10, the bottom area of the Bay below a given depth is computed. If the DO concentrations fall below the tolerance of benthic or demersal organisms, then that much habitat will be lost. For example, if the depth of the oxycline is 14 m (Table 10), then about 120 x $10^6 m^2$ of bottom area in CB-4 (14 percent) will be below the oxycline. If the oxycline moves upward to 12 m, then a total of 223 x $10^6 m^2$ (26 percent) will be below the oxycline. Thus, for a vertical movement of 2 m (from 14 m to 12 m) in the oxycline, 103 x $10^6 m^2$ (12 percent) of additional bottom in CB-4 will be covered with low DO water.

An estimate of the phosphorus liberated from the bottom sediments covered with anoxic waters can be be made by utilizing regeneration rates (Taft 1982) and the area of the bottom that is affected. The data are also

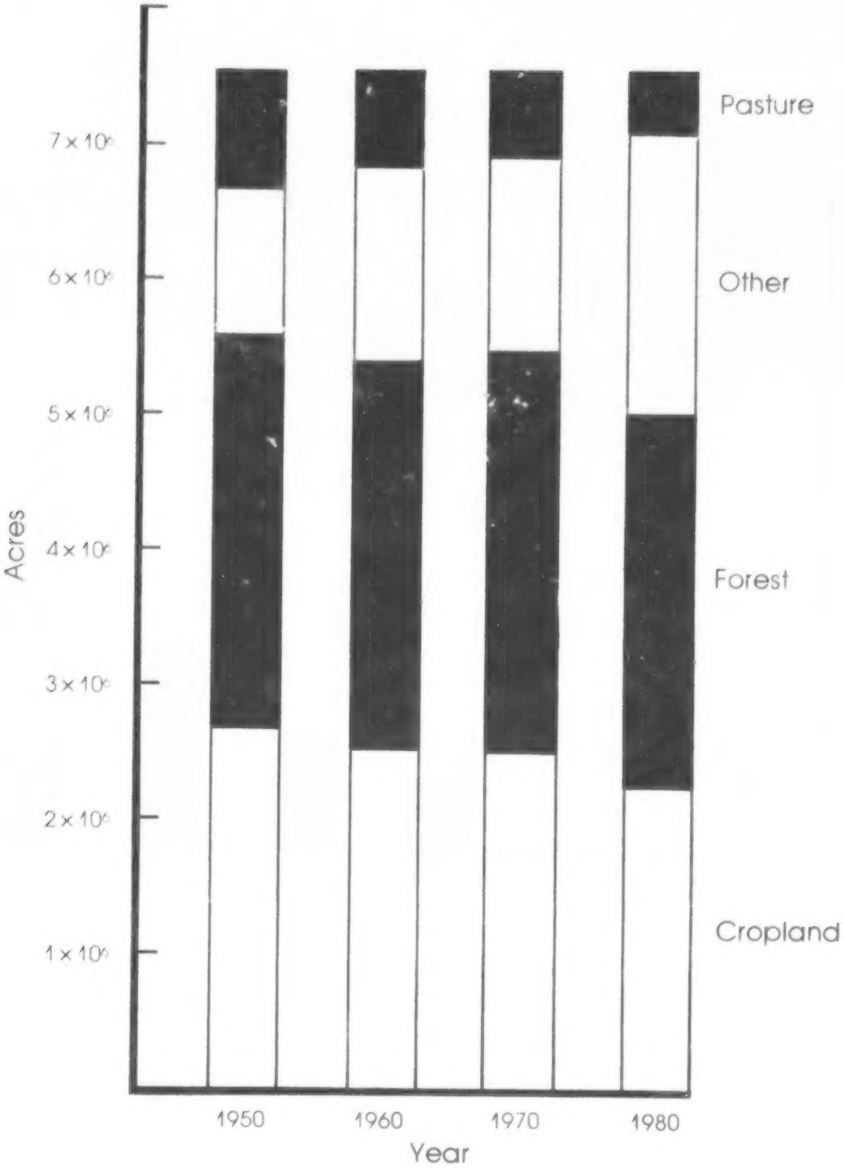


Figure 29. Land use in the upper Chesapeake - lower Susquehanna region.

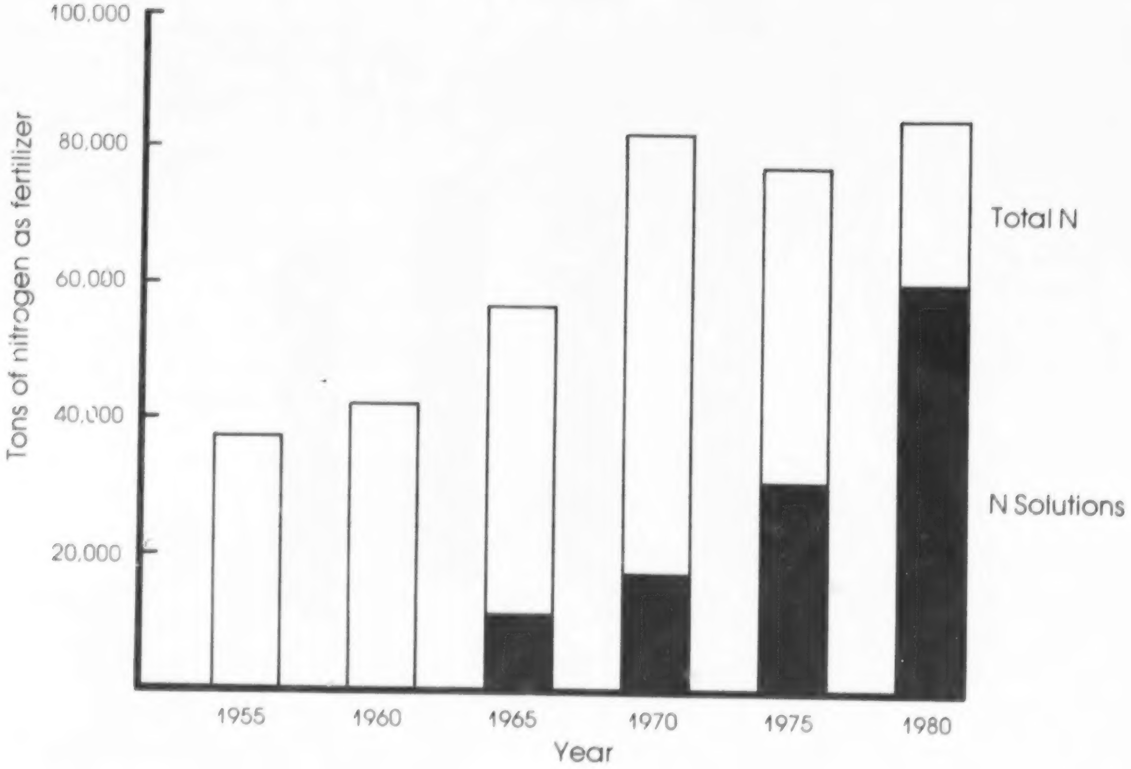


Figure 30. Fertilizer consumption in Pennsylvania.

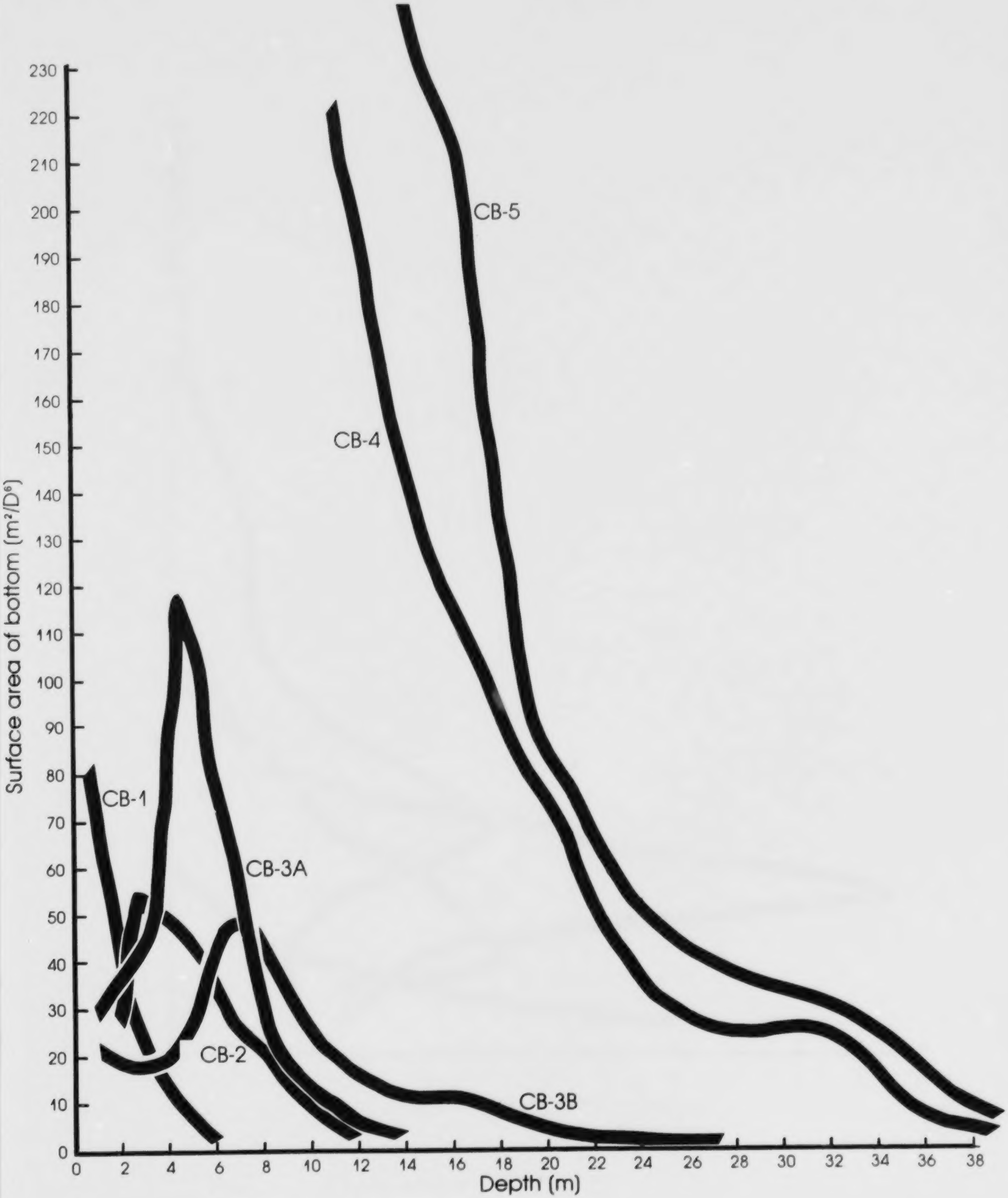


Figure 31a. Amount of bottom surface area at each depth from 0 to 40m.

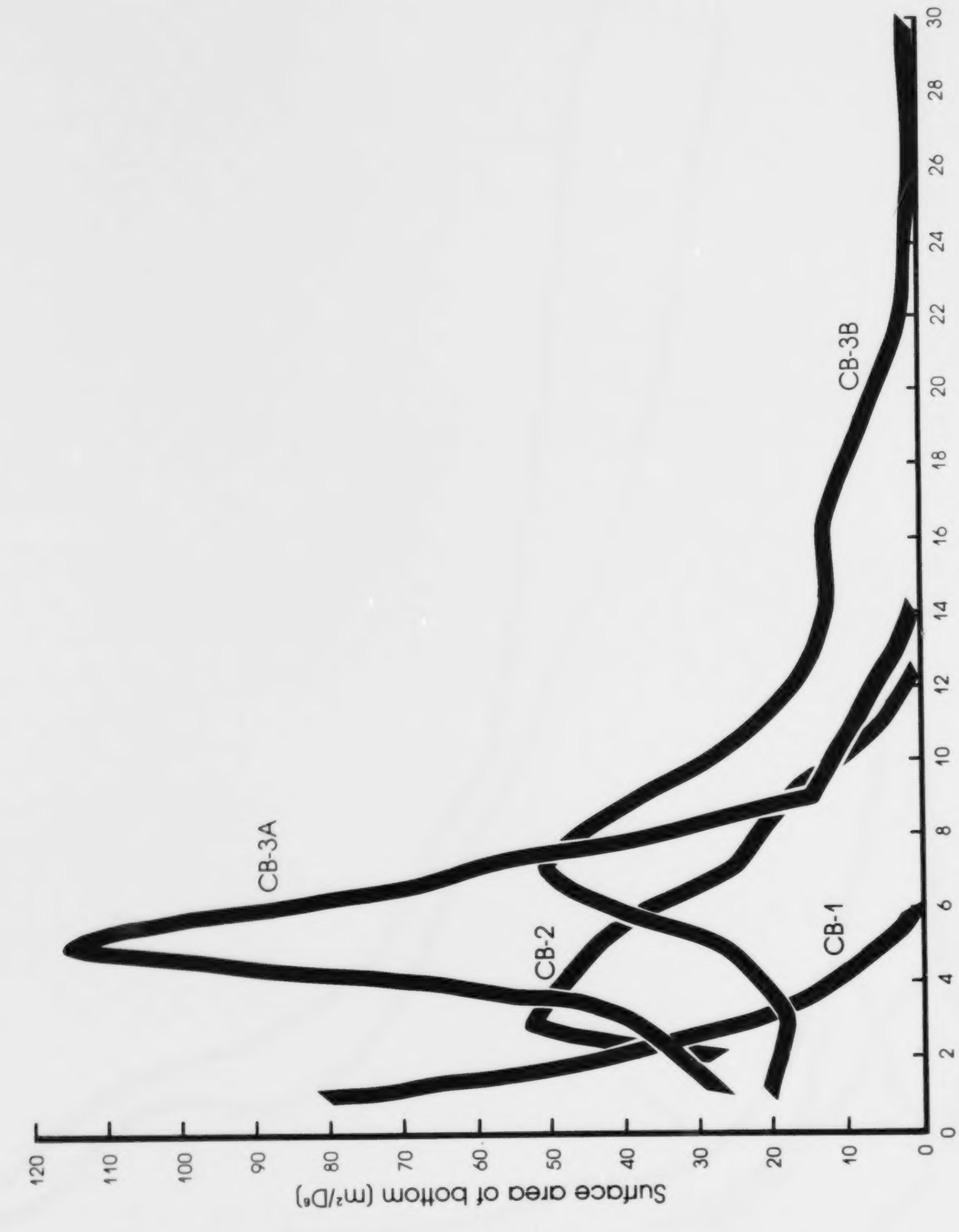


Figure 31b. Depth vs surface area of bottom.

TABLE 10. TOTAL PHOSPHORUS REGENERATION FOR CB-1,2,3,4,5 BY DEPTH ($>$ 8m)

Segment	Depth interval (m)	Area $m^2 \times 10^6$	Potential P-release	Total load
CB-1	8	0		
CB-2		22.66	2.10	47.59
CB-3a		26.02	3.76	97.84
CB-3b		89.92	3.76	338.10
CB-4		585.60	2.59	1516.70
CB-5		1031.60	4.15	4281.14
CB-2	10	5.60	2.10	11.76
CB-3a		12.10	3.76	45.50
CB-3b		52.89	3.76	198.87
CB-4		503.70	2.59	1304.58
CB-5		805.50	4.15	3342.83
CB-2	12	1.05	2.10	2.21
CB-3a		4.02	3.76	15.12
CB-4		223	2.59	577.57
CB-5		364	4.15	1510.60
CB-4	14	120		310.80
CB-5		220		913.00
CB-4	18	75		194.25
CB-5		89		369.35
CB-4	22	36		93.24
CB-5		50		207.50
CB-4	26	22		56.98
CB-5		35		145.25
CB-4	30	21		54.39
CB-5		28		116.20
CB-4	34	5		12.95
CB-5		16		66.40
CB-4	38	0.5		1.30
CB-5		2.0		8.30
CB-4	42	0.5		1.30
CB-5		0.6		2.49
CB-4	46	0.5		2.03

presented in Table 10. As an example, with an oxycline in CB-4 at 14 m, 310 kg P day^{-1} are liberated; if the oxycline migrates to 12 m, 577 kg P day^{-1} are liberated. The bottom can serve as an important source of P, and increases of this magnitude may be important to the nutrient dynamics of the estuary (Taft 1982).

Other investigators have provided insight into the dynamic nature of the oxycline. Flemer and Biggs (1971) (Figure 32) found that variations of 1 m in the oxycline could occur on a time scale of minutes, presumably because of internal waves. Carpenter and Cargo (1957) proposed that occassionally observed "crab wars" were caused by NW wind events with durations of hours to days. Cargo and Biggs (1969) measured DO twice a week for 3 years at a deep water station in CB-4 and found wide variations in both DO concentration and the depth of the oxycline on a time scale of days to weeks (Figure 33). Biggs (1967), in a study of Bay sediments in CB-4, found evidence of long-term changes (years to decades) of the levels of the oxycline. The results of these studies indicate that both short-term and long-term fluctuations occur in DO concentrations and the depth of the oxycline. Even against the background of these fluctuations, the temporal and spatial extent of anoxia observed in the late seventies and early eighties is unprecedented in the historical period.

SUMMARY

This section has focussed on changes in DO concentration in Chesapeake Bay. The volume of low oxygen water in the Bay during summer increased markedly between 1950 and 1980. Short- and long-term fluctuations have been observed. The relationship between the salinity gradient and the DO gradient has been established empirically. Deviations from this relationship, such as those observed in May 1980, indicate the significance of factors other than stratification that influence oxygen concentrations. This relationship also draws attention to the importance of surface layer oxygen concentrations in determining the flux rate to, and concentration in, the lower layer. Observations of increased nutrient concentrations and turbidity in the northern reaches of Chesapeake Bay are consistent with the notion that the different DO concentrations in 1950, 1957, and 1980 are directly related to increased oxygen demand rather than to differences in Susquehanna River flow effects on stratification. Two of man's activities on the watershed could contribute to the observed nutrient increases: increased use of nitrogen fertilizer and a shift in land use toward non-agricultural activities.

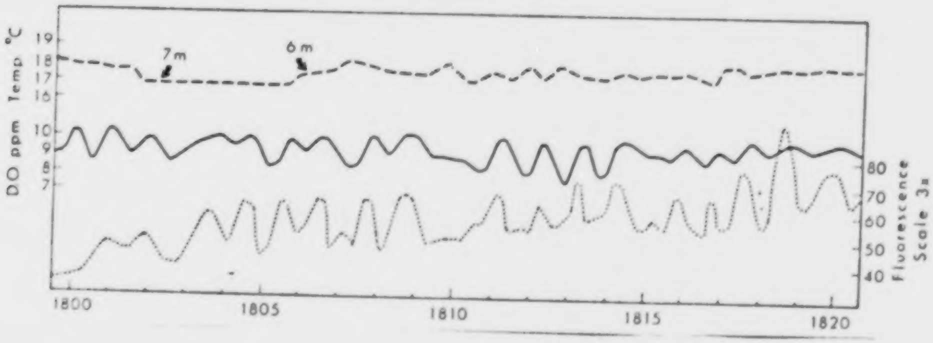


Figure 32. Short-term variations in fluorescence and dissolved oxygen from 1800 to 1820 hr, 5 June 1968, upper Chesapeake Bay. Legend: long-dashed line = temp., short-dashed line = fluorescence, and solid line = dissolved oxygen (from Flemer and Biggs 1971).

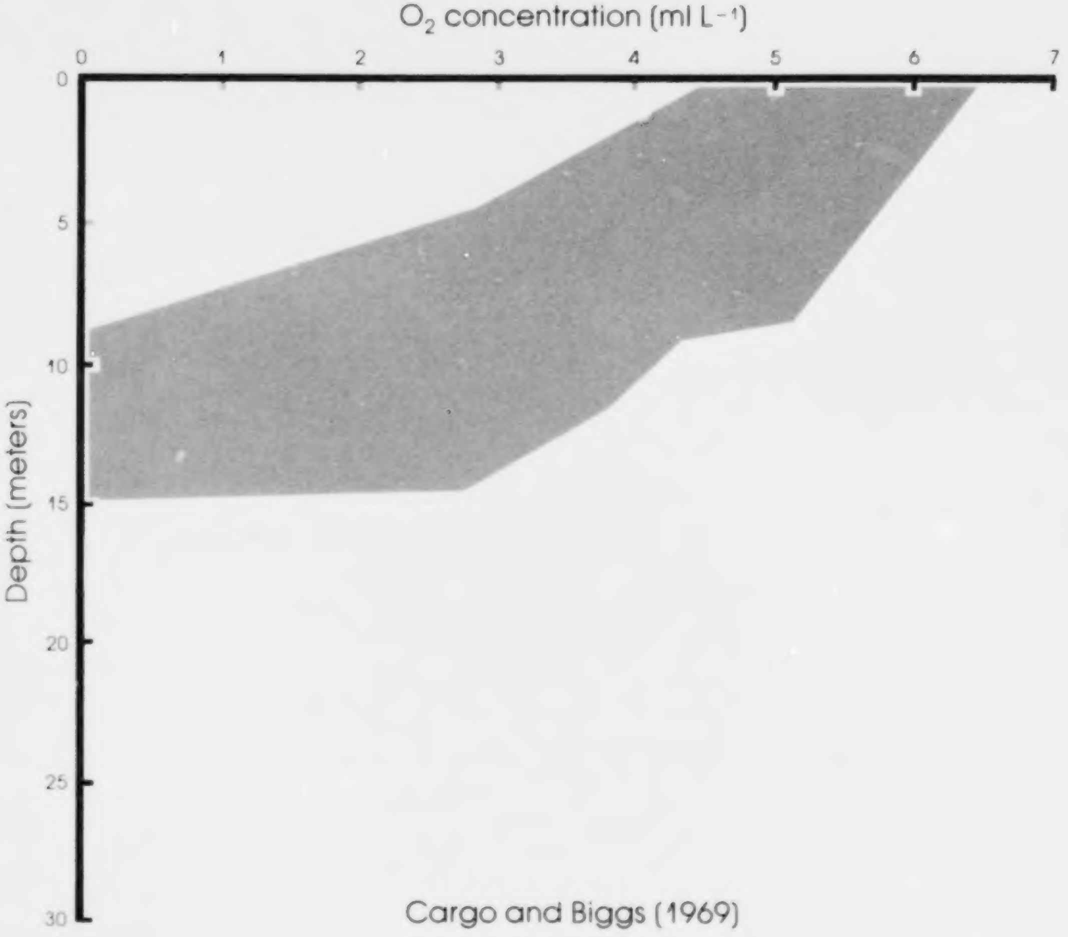


Figure 33. Cove Point O_2 (ml L^{-1}) in 1961

SECTION 6
METHODOLOGY FOR DEVELOPING DEGREE OF METAL CONTAMINATION

INTRODUCTION

To assess trends for the occurrence of metals in Chesapeake Bay, one can use sediment cores documenting changes over time. A sediment core, analyzed for trace metals and with an established geochronology, can estimate trace metal inputs, assumming no diagenetic migration of metals through the length of the core. Such an analysis must be conducted carefully, for the burrowing activities of benthic organisms in aerobic environments can disturb the sedimentary record, create an "artificial" ^{210}Pb distribution, and influence trace metal patterns.

The CBP conducted a core study of the Bay (Helz 1980) to ascertain historical trends in the presence of metals. These cores have been examined for ^{210}Pb metal analyses and degree of bioturbation (Figure 34). If one assumes that ^{210}Pb is introduced uniformly to the Bay by atmospheric processes, then the depth-integrated ^{210}Pb concentrations for each core will depend on the rate and depth of biological mixing. Rapid mixing to great depths will yield a high total integrated ^{210}Pb concentration, while slow mixing to only shallow sediment depths will yield a low total value. The depth-integrated ^{210}Pb concentrations from the cores of Helz (1980) were plotted as a function of sedimentation rate. The depth-integrated values exhibit a rough linear trend. In the absence of other radiogenic analyses to verify the ^{210}Pb sedimentation rates, the conservative interpretation is to tentatively discard the ^{210}Pb profiles that exhibit high total integrated values (cores 6, 24, 55, 62, 63, 64, and 86). Data on ^{137}Cs are available from core 24 and show a broad peak that is inconclusive in verifying the ^{210}Pb chronology of that core.

Cores 52, 99, and 102 are eliminated from consideration because the ^{210}Pb profiles near the surface of the cores show no decrease, indicating intense mixing of sediment to a depth equivalent to 50 years of deposition. Although cores 14, 83, and 85 exhibit exponential ^{210}Pb profiles, they are eliminated from further consideration because X-ray analysis of box cores from these sites shows deep bioturbation, and there are frequent metal "spikes" with depth in the cores. Cores 4, 18, and 60 exhibit exponential ^{210}Pb profiles; have low ^{210}Pb depth-integrated concentrations; exhibit lower, moderate bioturbation; show no metal spikes; and have a relatively uniform lithology. In addition, core 4 has ^{137}Cs data that verify the ^{210}Pb sedimentation rate. Some or all of the cores, which have been eliminated from consideration here, may in fact, possess excellent ^{210} Pb chronologies. In the absence of confirming radiogenic data to verify the ^{210} Pb dates on the deleted cores, only cores 4, 18, and 60 will be considered further.

Several techniques have been devised to estimate the degree of contamination of sediments by metals. Turekian and Wedepohl (1961) developed data on the average concentration of trace metals in various sedimentary rocks. Often contamination in modern sediments is identified by the ratio of metal in the sample to metal in an average shale (or sandstone); this ratio is termed the Wedephol ratio. The problem with this technique is that there is no compelling evidence that natural James River sediments, for example, should have the same concentration of a particular metal as the average of all of the earth's shales. Other investigators

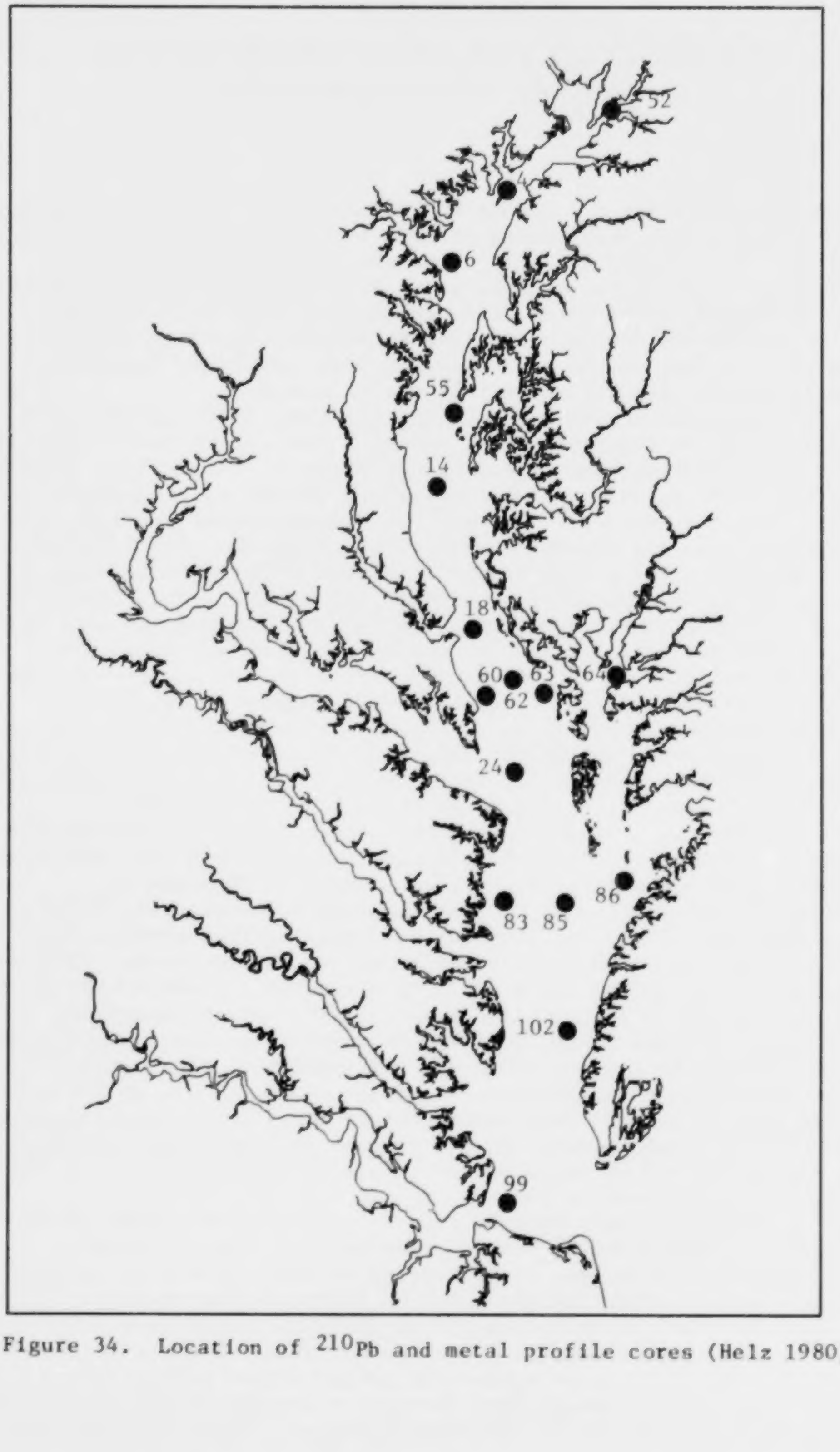

52
4
6
55
14
18
60
63
64
62
24
86
83
85
102
99

Figure 34. Location of ^{210}Pb and metal profile cores (Helz 1980).

have chosen to normalize trace metal concentrations to some metal present in sediments in such high concentrations that it is unlikely that anthropogenic sources could influence it to a significant degree.

The metal frequently chosen to ratio against is iron. Unfortunately, iron is relatively mobile after burial, and significant quantities can migrate through sediment pore waters. Still other investigators suggest normalizing the metal content of sediment samples to the grain size of the sediment. There is usually a strong inverse correlation between sediment size and metal content. Grain size, though, is only a rough indicator of particle surface area, sediment organic content, and sediment mineralogy, any or all of which are the probable cause of high metal concentration in fine sediments.

Chesapeake Bay Program scientists have applied a different approach to the estimation of the degree of metal contamination in Chesapeake Bay sediments. By using pre-colonial Chesapeake sediments, we have avoided the use of potentially mobile metals like iron; by measuring silicon and aluminum, we have simultaneously accounted for sediment grain size, and mineralogy [sands are mostly quartz, silts, and clays (as size terms)] may be either quartz or clay minerals.

SCENARIO

The sediments deposited in the Chesapeake are a mixture of materials derived from the rivers, shore erosion, the organisms growing in the Bay, the ocean, and the atmosphere. The proportion of each component depends principally on proximity to ocean and river sources, with erosional, biogenic, and atmospheric inputs contributing the strongest signals in depositional areas where they are not overwhelmed by river or ocean inputs. Over time, the relative importance of different sources has changed.

Imagine the 66,045 km^2 Susquehanna River basin just prior to its exploration by John Smith. The watershed was probably 95 percent covered by mature forests with a few clear areas that had recently been burned over. Biggs (1981) has estimated that the seasonal distribution of freshwater discharge from the Susquehanna to the Chesapeake was different then; springtime peak discharges may have been 30 percent lower than at present while summer and autumn low flows may have been 10 percent higher. This is because direct runoff as overland flow is much lower for forested than for agricultural areas; conversely, infiltration, which contributes water to the groundwater system, is higher under forest cover.

In the mid-Atlantic region of the United States, the principal rock weathering process is mineral hydrolysis. Total hydrolysis, which occurs under intense, tropical, chemical, weathering, produces a forest soil consisting of iron and aluminum hydroxides, and a solution rich in silicon which is carried away in the rivers. In temperate regions, where both rainfall and mean temperature are lower, the intensity of the hydrolysis process is diminished. Partial hydrolysis produces forest soil with a principal residual clay mineral of kaolinite [$Si_2O_5Al_2(OH)_6$]. The soil is rich in Fe, with a Si/Al ratio of approximately one, and the material carried by the rivers rich in Si (Table 11).

As the forests of the Susquehanna watershed (and all of the other watersheds of the Chesapeake) were cleared, direct runoff increased. Combined with increased erosion, this runoff caused higher sedimentation rates in the Chesapeake by carrying more materials to the Bay. Lystrom et al. (1978) have estimated background (natural) concentrations of materials in the Susquehanna disharge before agricultural activity. Particulate sediment yield ranges between 7.4 and 104 tons km^{-2} with present land use; prior to extensive agricultural activity, the range was from 5.7 to 29 tons km^{-2}. Table 12 illustrates the observed and simulated pristine ranges for a number of water quality parameters in the Susquehanna Basin. The increased suspended sediment yields from upland areas were comprised principally of Al-rich soils that had accumulated under, and had been protected by, the forest cover. Thus, recently-deposited sediments of the main Bay, near the Susquehanna, should be more Al-rich than those down-bay. Core sediments, at a given location, should be Al-rich near the surface and increasingly Si-rich with depth (age) in those areas of the Bay with a more or less constant, or small total contribution of Al and Si to the sediments from shore erosion, atmospheric, and biogenic sources.

SILICON-ALUMINUM RATIO

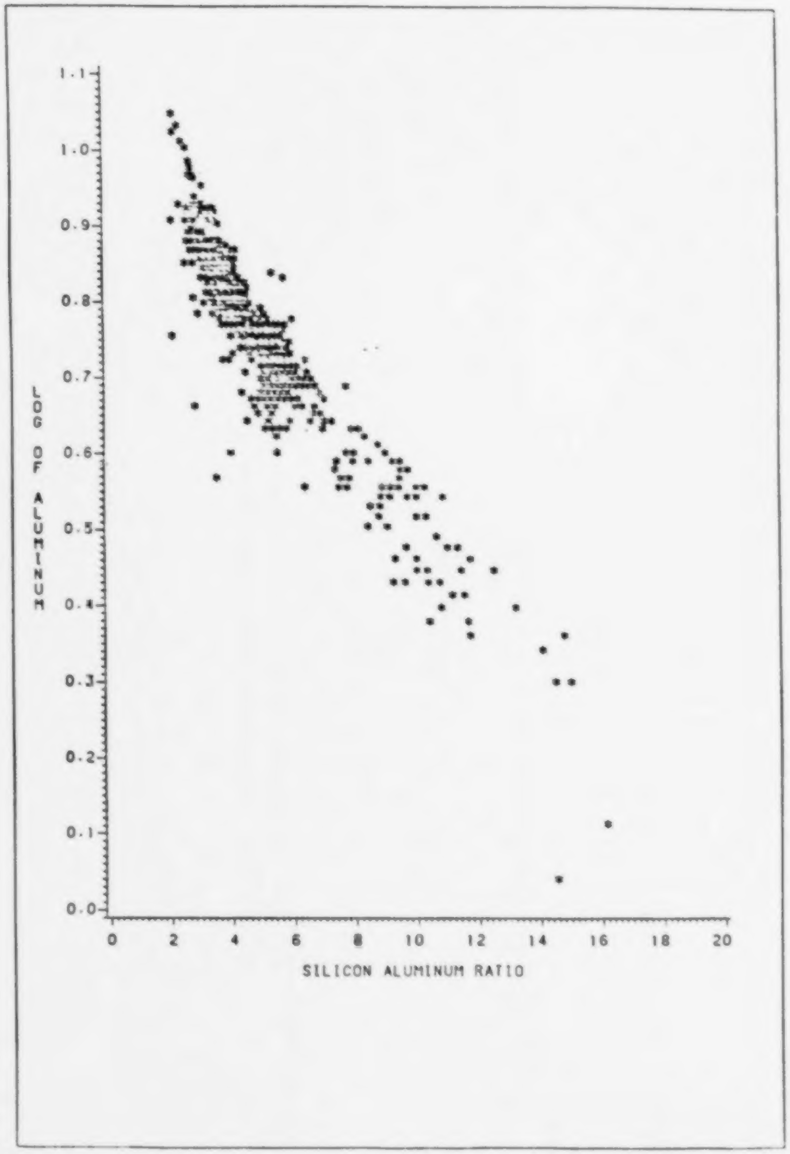
In geochemistry, there are relatively few cases of normal elemental distribution; instead, the distribution in rocks, sediments, soils, and waters most often approximates a lognormal function (Ahrens 1957). Helz et al. (1980) found that all elements analyzed in their Bay samples exhibited an approximate lognormal frequency distribution.

A plot of Helz et al. (1980), Al and Si data for bulk sediments of the Bay as a function of Si/Al ratios, is presented in Figure 35. These bulk samples range from silty clays to sands. Si/Al ratios and mean weights for average shale and average sandstone (Turekian and Wedepohl 1961) are also plotted. There is a continuous size and composition gradient between shales and sandstones and, given a lognormal distribution of elemental abundance, one would expect a geochemical gradient from shales to sandstones; that is, we should be able to connect the shale and sandstone points with a straight line on the figure. For Al (Figure 35a), the Chesapeake bulk sediment data closely approximate the continuum between average shale and average sandstone, but for Si (Figure 35b), the relation is poor. Either Si is not lognormally distributed in the Turekian and Wedepohl shale data, with a significant loss of Si occurring during the interval between sedimentation and lithifiction, or the Susquehanna basin is strongly enriched in Si. Regardless of the reason for the high Si content of Chesapeake sediments, it seems apparent from the illustrations that a continuous gradient of Al content is principally responsible for changes in the Si/Al ratio. Modern Susquehanna bed sediment (Helz core SUS) and the average of over 3000 modern streams mud samples (Keith et al. 1967) are also illustrated on Figure 35. Both fall within the continuum of Bay sediment values.

Figure 36 illustrates the Si/Al ratios for Helz cores 4, 18, and 60 plotted as a function of ^{210}Pb-derived age before the present. Si/Al ratios generally decrease toward the top (present) in each core, as is predicted by the scenario of increasing land clearance, surface erosion, and delivery of Al-rich, fine materials to the Bay from the Susquehanna drainage basin. Important natural and man-made events, and trends in the Susquehanna drainage basin are presented on the time axis (data from Brush and Davis 1981).

METAL CONTENT AND SI/AL RATIOS

The use of Si/Al weight ratios as an independent variable against which to measure the concentration gradient of trace metals relies on the



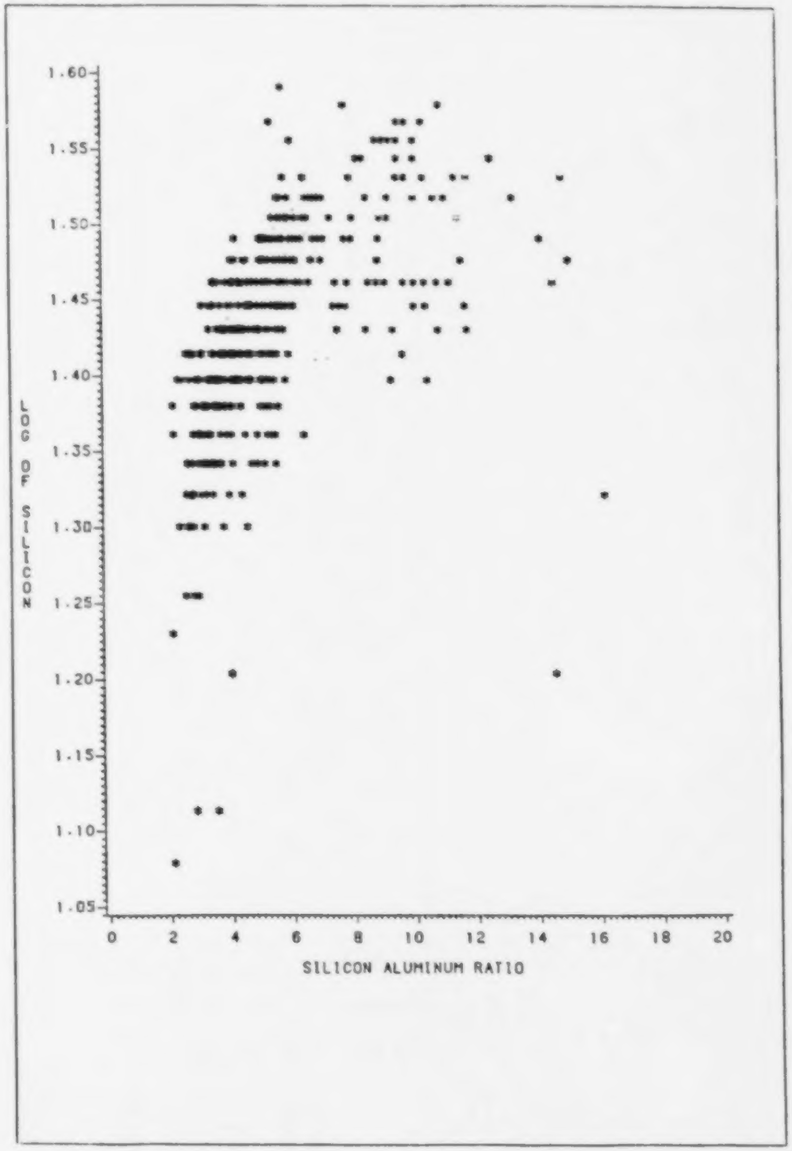


Figure 35a. Aluminum concentration as a function of the Si/Al weight ratio.

Figure 35b. Silicon concentration as a function of the Si/Al weight ratio.

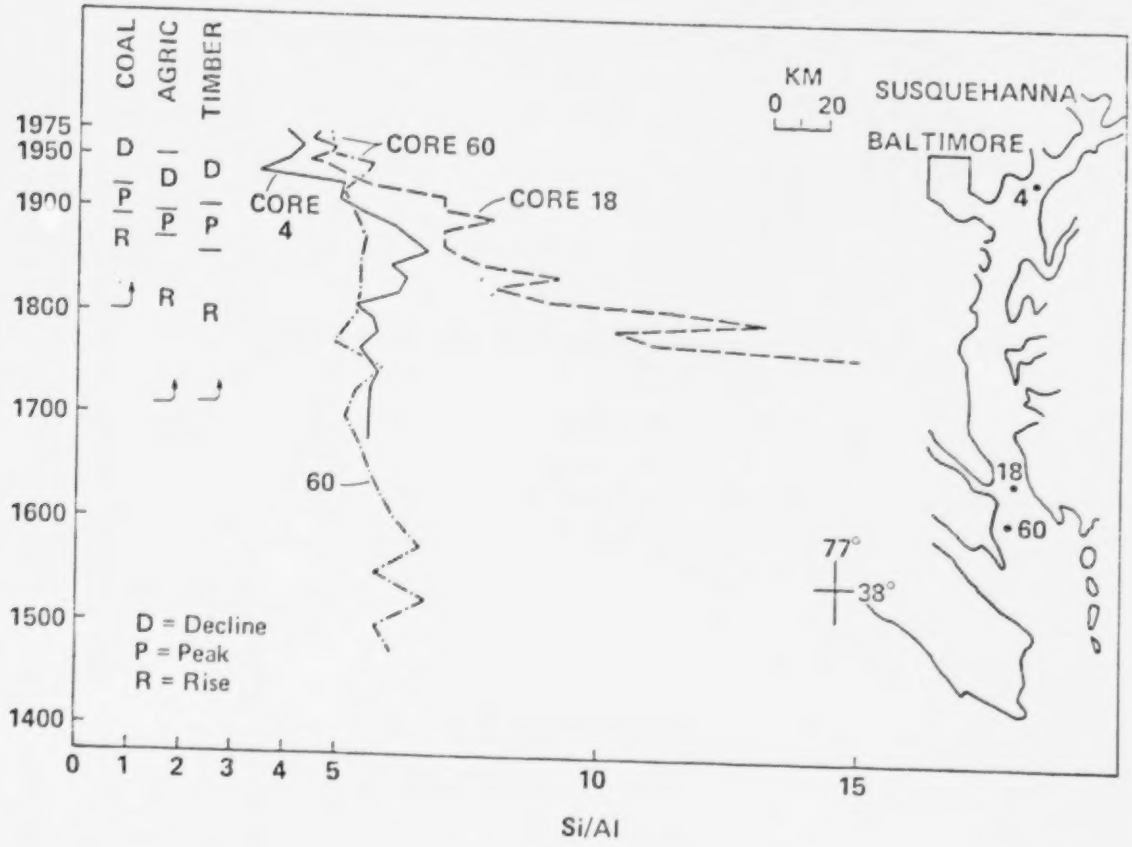


Figure 36. Silicon -aluminum weight ratio distribution in ^{210}Pb dated cores from Chesapeake Bay (from Helz 1981).

TABLE 11a. ANALYSIS OF A QUARTZ-FELDSPAR BIOTITE GNEISS AND ITS WEATHERING PRODUCTS (%). COLUMN I REPRESENTS FRESH ROCK, AND II, III AND IV REPRESENT GRADUALLY INCREASING DEGREES OF WEATHERING OF THE MOTHER ROCK (FROM GOLDICH 1938)

Oxide	I	II	III	IV
SiO_2	71.54	68.09	70.30	55.07
Al_2O_3	14.62	17.31	18.34	26.14
Fe_2O_3	0.69	3.86	1.55	3.72
FeO	1.64	0.36	0.22	2.53
MgO	0.77	0.46	0.21	0.33
CaO	2.08	0.06	0.10	0.16
Na_2O	3.84	0.12	0.09	0.05
K_2O	3.92	3.48	2.47	0.14
H_2O	0.32	5.61	0.54	0.58
Others	0.65	0.56	0.54	0.58
Totals	100.07	99.71	99.70	100.11

TABLE 11b. GENERAL CALCULATIONS OF GAINS AND LOSSES OF CHEMICAL ELEMENTS DURING WEATHERING (%) FROM DATA GIVEN IN TABLE 11a (FROM KRAUSKOPF 1967)

Oxide	I	III	A	B	C
SiO_2	71.48	70.51	55.99	-15.49	-22
Al_2O_3	14.61	18.40	14.61	0	0
Fe_2O_3	0.69	1.55	1.23	+0.54	+78
FeO	1.64	0.22	0.17	-1.47	-90
MgO	0.77	0.21	0.17	-0.60	-78
CaO	2.08	0.10	0.08	-2.00	-96
Na_2O	3.84	0.09	0.07	-3.77	-98
K_2O	3.92	2.48	1.97	-1.95	-50
H_2O	0.32	5.90	4.68	+4.36	+1360
Others	0.70	0.54	0.43	-0.27	-39

Source: Introduction to Geochemistry, with permission of McGraw-Hill Book Company. Copyright 1967 by McGraw-Hill, Inc.

TABLE 11c. Si/Al RATIOS CALCULATED FROM TABLE 11a

	I	II	III	IV
Wt. % Si	33.4	31.3	32.2	25.3
Wt. % Al	4.7	5.6	5.9	8.4
Si/Al	7.1	5.6	5.5	3.0

TABLE 12. OBSERVED RANGES OF WATER QUALITY YIELDS, CONCENTRATIONS, AND BACKGROUND RANGES SIMULATED BY REGRESSION MODELS. BACKGROUND RANGES ARE CALCULATED BY HOLDING CULTURALLY AFFECTED VARIABLES CONSTANT AT ZERO (MODIFIED FROM LYSTROM ET AL. 1978)

Water quality characteristic	Observed Range		Simulated Background Range	
	min.	max.	min.	max.
Sediment yield (m tons Km^{-2})	7.4	104	5.7	29
Sediment concentration (mg L^{-1})	13.3	295	13.1	102
Dissolved solids yield (m tons km^{-2})	11.7	108	5.9	12.6
Dissolved solids conc. (mg L^{-1})	29	282	17.4	29.6
Av. Nitrogen conc. (mg L^{-1})	.40	1.59	.15	.46
NO_3 concentration (mg L^{-1})	.15	7.45	.13	.69
NO_3 yield (m tons km^{-2})	.09	3.1	.04	.15
Av. Phosphorus conc. (mg L^{-1})	.02	1.24	.01	.14
Phosphorus yield (m tons km^{-2})	.01	.12	.01	.01
PO_4 concentration (mg L^{-1})	.01	.20	.00	.01

following assumptions:

- There is a continuous gradient in Chesapeake sediments from fine (Al-rich) to coarse (Si-rich) material. Evidence for this statement is the plot of Si and Al in Figure 35 (a and b).
- Trace metals can be represented by a lognormal distribution. Evidence for this statement for the earth's crust is provided by Ahrens (1954), for Chesapeake trace metals by Helz (1981), and for Susquehanna stream muds by Keith et al. 1967.
- There is a continuous gradient of both trace metal and Si/Al ratios in Wedepohl shales and sandstones; that is, one can connect the metal -- Si/Al shale and the metal -- Si/Al sandstone compositions with a straight line on a log plot.
- There is no significant migration of metal during early diagenesis. For some metals, notably Mn and Co, there is strong evidence that significant migration of metal from buried sediment towards surface sediments (causing surface enrichment) does occur. For a few (notably Cu), the data are conflicting, and for most (Zn, Cr, V, Ti, Zr, Ni, Pb), the assumption is arguably valid.

Given the stated conditions, a model which separates estuarine sediments into three classes based on their metal content and their Si/Al ratios can be developed. These classes include: impoverished (compared to Wedepohl ratios); enriched (compared to Wedepohl ratios); and enriched (anthropogenic) (compared to pre-pollution sediments). To evaluate a sample in terms of the three metal components, the following information is required: (1) Wedepohl shale and sandstone values for Si, Al, and each metal of interest; and (2) a statistically significant regression line for log metal as a function of Si/Al for pre-pollution sediments. Given that information, one can construct a diagram for each metal [Figure 37 illustrates the process with Cr (37a) and Zn (37b)] in which all samples plot as impoverished, enriched naturally, or enriched anthropogenically.

The equations for Wedepohl and Chesapeake lines are presented in Table 13a. For each sample and each metal with an observed Si/Al ratio, one can compute:

$$\frac{C_o - C_p}{C_p} = C_f \text{ (contamination factor)}$$

where: C_o = surface sediment concentration and, C_p = predicted concentration.

The predicted concentration of a metal is derived from the statistical relation between the Si/Al ratio and the log metal content of old, pre-pollution sediments from the estuary. Surface sediments whose observed metal content is greater than the predicted value are considered to be contaminated. One can consider the C_f value to be a "percentage exceedance." When the observed metal concentration is much less than the predicted value, the $C_f < 0$; when observed and predicted are the same, the $C_f = 0$; and when the observed exceeds the predicted value, then $C_f > 0$. The predicted Wedepohl metal concentration, predicted Chesapeake concentration, and the observed concentration for cores 4 and 60 are illustrated in Figure 38 for Cr and Zn. Zinc contamination began in the last quarter of the 19th century, coincident with peak land clearance due to timbering and agriculture as well as coal mining in the Susquehanna drainage basin. Cr is illustrated as a metal that shows no historic enrichment in the cores. Brush (1981) has found a similar excursion of Zn concentration, beginning in the early 18th century (pollen dated) on the Susquehanna flats.

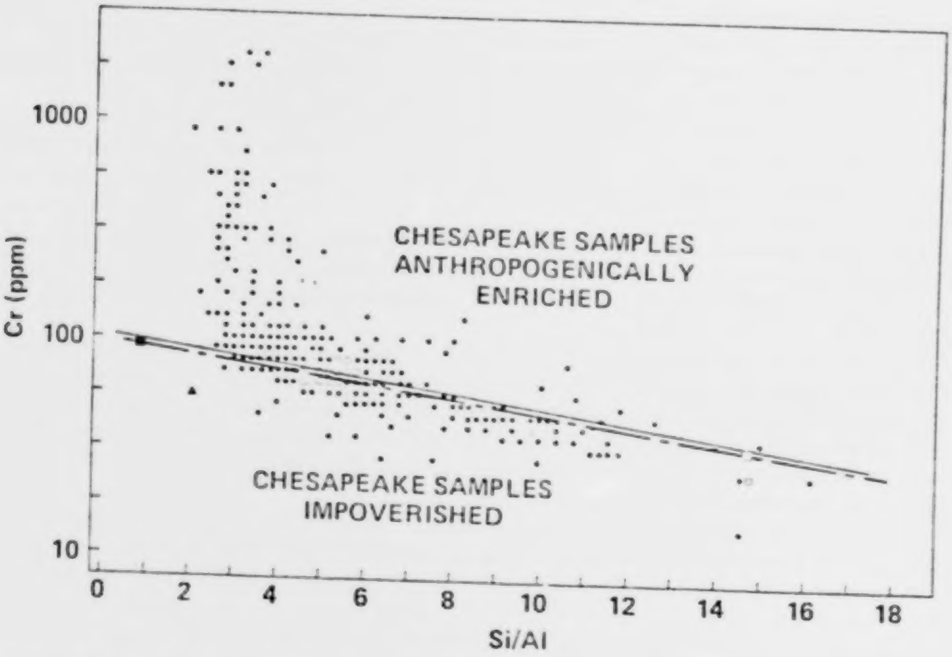


Figure 37a. Chromium vs. Si/Al in Chesapeake Bay sediments; 303 hidden observations (Helz 1981).

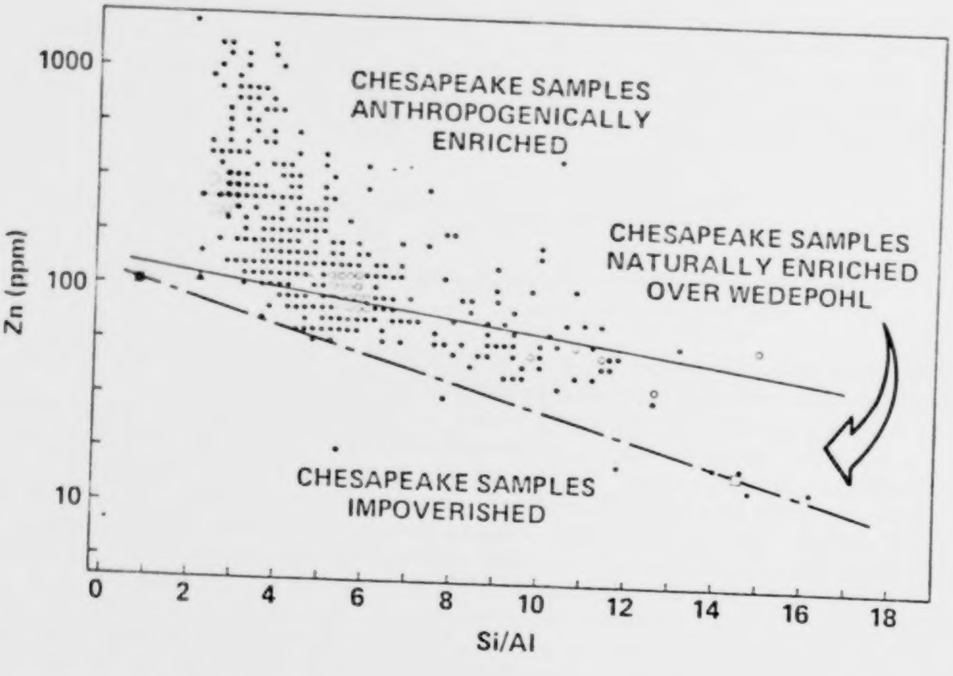


Figure 37b. Zinc vs Si/Al in Chesapeake Bay; 232 hidden observations (Helz 1981).

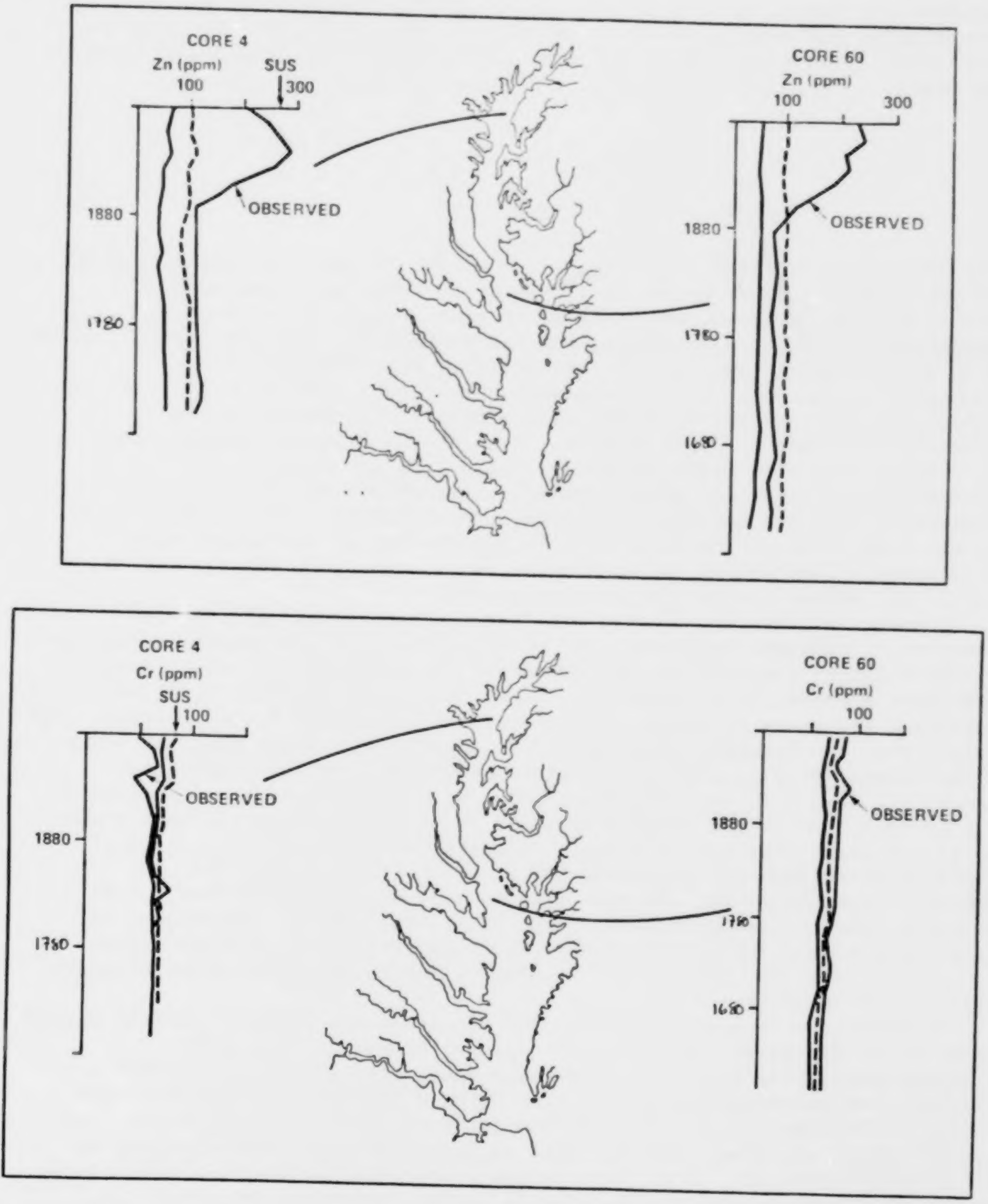


Figure 38. Zinc (Zn) and chromium (Cr) concentrations (ppm) in Chesapeake Bay sediments.

CONTAMINATION INDEX

The contamination index (C_I) for surface sediments by metals can be developed by combining data on the anthropogenic concentration of individual contaminants and summing these contaminant factors (C_f). The C_f value for each metal is computed and all of the C_f values for a given sediment sample are summed to produce the index of contamination, C_I:

$$C_I = \sum_{n=1}^{n} C_f = \sum_{n=1}^{n} \frac{C_o - C_p}{C_p}$$

The contamination index, C_I, for a large number of surface samples from the Patapsco and Elizabeth Rivers is presented in Table 14. This method of characterizing estuarine sediments gives equal weight to all metals, regardless of absolute abundance, and has no inherent ecological significance. When this index is combined with bio-toxicity data (Chapter 3), its biological importance can be assessed. Where individual metal C_f's exceed 1.0, they contain specific metal concentrations that exceed natural Chesapeake sediments by 100 percent. Most of the Patapsco samples have C_I's which exceed 10 (1000 percent). These C_f's are based on the correlation of Si/Al and metal content. They should be interpreted as departures from the natural, deep metal concentration. The correlation of metals with Si/Al ratios should not be interpreted as causation, merely covariance. Controlling parameters for metal concentrations may well be redox, pH, organic, or sulfur species present.

Trace metal, Si, and Al data are frequently not available for the majority of sediment analyses. One cannot then apply the equations developed in Table 13a to the majority of sediments. As an alternate, one can use the predicted Wedepohl metal concentration at some representative Si/Al ratio for estuarine sediments to estimate the contamination factor for each metal. The Si/Al ratio for Wedepohl shale (0.91) is considerably lower than the lowest Si/Al values found in surface sediments of the Bay and its tributaries (geometric mean 4.4, max. 21, min. 1.8). We have selected a Si/Al ratio of 3.0 (2.55.D - below the mean) upon which to predict surface sediment trace metal concentrations and to compute contamination factors for each metal where no Si/Al data are available. This selection minimizes the contamination factor for sediment samples with Si/Al greater than 3, and maximizes the contamination factor for Si/Al less than 3. Therefore, in areas such as the Susquehanna Flats, which is very sandy, the contamination factor is minimized, while in silty areas like the Northeast River channel, this factor is maximized.

A computer search was conducted for all available surface sediment metals data in the Chesapeake and its tributaries. Predicted Chesapeake concentrations (for Si/Al = 3) were used where significant and predicted Wedepohl concentrations were used (for Si/Al = 3) when no Chesapeake values could be developed to calculate contamination factors for each metal. The sum of these individual factors; that is, the degree of contamination, is plotted in Figure 39. This illustration represents our best estimate, using all available data, and of the potential metal contamination, from anthropogenic sources, of the surface sediments of the Bay and its tributaries. No data exist near to shore, and large local increases should be expected close to outfalls. These variations have not been indicated on Figure 39.

TABLE 13. TRACE METAL VERSUS Si/Al RELATIONS. WEDEPOHL LINE FOUND BY DETERMINING EQUATION THAT FITS SHALE AND SANDSTONE AVERAGES. CHESAPEAKE LINE FOUND BY BEST FIT OF PRE-1700 HELZ CORE DATA

Metal	Wedepohl line (shale - sandstone)	Chesapeake Line (pre-industrial samples)
	a). Wedepohl and Chesapeake Lines for Metals	
V	$\log V = -.059\ \mathrm{Si/Al} + 2.16$	$\log V = -.028\ \mathrm{Si/Al} + 2.15$
Cr	$\log Cr = -.03\ \mathrm{Si/Al} + 1.98$	$\log Cr = -.033\ \mathrm{Si/Al} + 2.04$
Ni	$\log Ni = -.111\ \mathrm{Si/Al} + 1.93$	$\log Ni = -.012\ \mathrm{Si/Al} + 1.60$
Zn	$\log Zn = -.057\ \mathrm{Si/Al} + 2.03$	$\log Zn = -.029\ \mathrm{Si/Al} + 2.13$
Cu	$\log Cu = -.265\ \mathrm{Si/Al} + 1.89$	Not significant
Co	$\log Co = -.129\ \mathrm{Si/Al} + 1.40$	Not significant
Pb	$\log Pb = -.030\ \mathrm{Si/Al} + 1.29$	$\log Pb = -.032\ \mathrm{Si/Al} + 1.33$
Hg	$\log Hg = -.132\ \mathrm{Si/Al} - .28$	No data
As	$\log As = -.284\ \mathrm{Si/Al} + 1.37$	No data
Se	$\log Se = -.074\ \mathrm{Si/Al} - .15$	No data
Cd	$\log Cd = -.171\ \mathrm{Si/Al} - .36$	No data

b). Predicted Metal Concentration for Si/Al = 3, found by solving equations in above Table for Si/Al = 3

Metal	From Wedepohl Line	From Chesapeake Line
V	96 ppm	116 ppm
Cr	77	87
Ni	39	36
Zn	72	110
Cu	12	--
Co	10	--
Pb	16	17
Hg	0.2	--
As	3	--
Se	0.4	--
Cd	0.1	--

TABLE 14. CONTAMINATION FACTORS (C_f) AND DEGREE OF CONTAMINATION (C_I) FOR SURFACE SEDIMENTS FROM THE PATAPSCO (LETTER DESIGNATIONS) AND THE ELIZABETH RIVERS (NUMBER DESIGNATION)[1]

STA[1]	C_f[2] V	C_f Cr	C_f Ni	C_f Zn	C_f Co[3]	C_d[4]
A	.471	.323	1.69	2.84	4.67	10
B	.173	.855	.630	2.28	5.17	9
E	.647	1.24	.907	6.22	6.14	15
F	1.76	1.60	.879	3.82	4.00	12
G	.501	3.40	1.20	3.18	3.89	12
H	1.09	2.74	.879	4.63	4.89	14
I	2.41	5.25	1.23	6.81	3.60	19
J	2.71	5.48	1.27	7.64	3.89	21
K	.931	4.51	.916	5.10	2.43	14
L	1.05	4.33	1.36	6.74	6.83	20
M	.62	7.01	1.33	4.75	6.83	21
N	.199	22.30	1.06	6.69	2.00	32
O	.206	2.75	1.72	4.15	1.00	10
BH41	.160	.579	.486	2.37	7.00	11
BH43	.339	1.05	.750	3.46	6.71	12
BH44	.559	1.47	.611	4.10	6.67	13
BH45	.346	1.34	.542	3.90	6.00	12
BH49	.947	2.21	.667	3.86	2.71	10
BH50	.947	2.45	.972	4.42	3.71	13
BH51	.284	.975	.334	1.81	1.33	5
BH52	.794	2.75	.919	4.49	2.12	11
BH53	.709	2.29	.972	4.13	2.75	11
BH54	.638	3.14	.969	4.64	1.75	11
BH55	.565	5.16	1.03	4.78	2.00	14
BH56	.327	5.35	.500	2.83	1.14	10
BH57	1.39	4.28	1.11	6.68	2.00	16
BH58	1.24	3.60	1.14	5.27	1.50	13
BH59	1.09	3.19	1.08	3.31	1.50	10
BH60	.68	1.17	.441	1.67	.67	5
BH61	.504	3.12	1.08	3.02	1.14	9
BH62	.504	3.40	1.17	2.92	.86	9
136	-.128	0.030	-.261	-.375	2.60	2
137	.078	-.102	-.130	.056	1.00	1
138	-.221	-.055	-.314	.104	-1.00	-1
139	.225	.063	-.029	3.77	0.00	4
140	.069	.146	-.105	11.38	-1.00	10
142	.101	1.42	.375	5.07	9.00	16
143	.107	.396	.021	1.46	2.00	4
145	-.069	-.205	.082	1.89	-1.00	1
146	-.004	.118	.098	8.39	0.00	1

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[1] Data from Helz 1982.

[2]

$$C_f = \frac{C_o - C_p}{C_p}$$

[3] Co values computed from Wedepohl line, log Co = 0.129 Si/Ac + 1.30.

[4]

$$C_I = \sum_{n=1}^{n=6} C_f$$

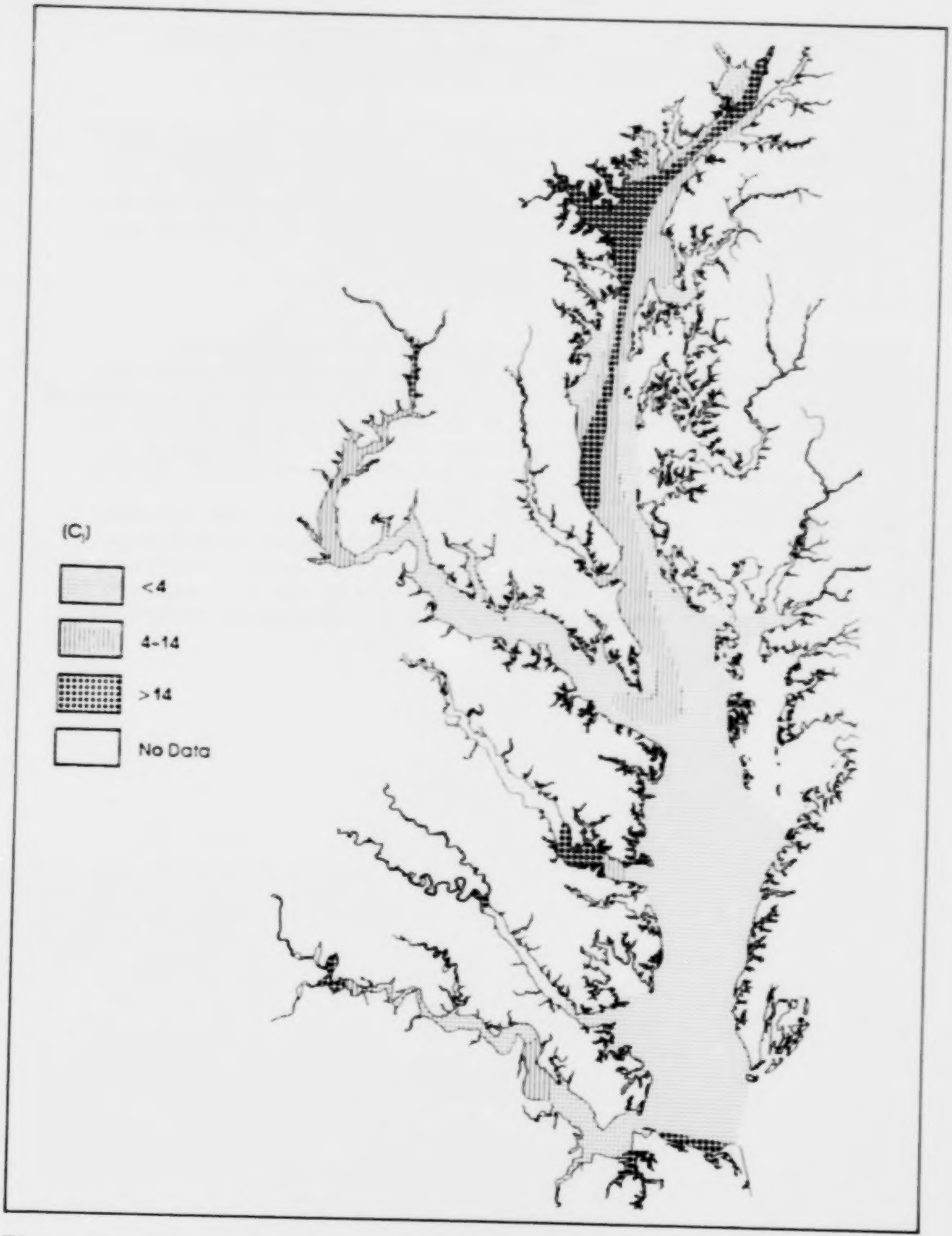
(C_I)
<4
4-14
>14
No Data

Figure 39. Degrees of metal contamination in the Bay based on the contamination index (C_I).

SECTION 7

LEVELS OF HEAVY METALS IN OYSTER TISSUE FROM MARYLAND AND VIRGINIA

Tables 15 through 21 show levels of Cr, Cd, Cu, Zn, and other metals and some pesticides found in the tissue of oysters from Chesapeake Bay waters. Data were collected by the Virginia State Water Control Board (VSWCB) and the Maryland Department of Human Health and Hygiene and were used in the CBP's assessment of metals and pesticides in shellfish and finfish (Chapter 1).

EXPLANATION OF METAL TABLES

The following tables summarize metals data for Chesapeake Bay segments. The data are presented for Bay main stem, western shore, and eastern shore tributaries. For the Bay main stem, information is available for dissolved and particulate metals in the water column (Tables 22, 23, and 24). Mean, minimum, and maximum concentrations of eight metals in sediments are shown in Table 25. Bottom sediment contamination factors (C_f and C_I) are presented in Tables 26 and 27.

Similar data are presented for other segments, except that no water column data are available for any areas except four major western shore tributaries (Table 28). These tables include bed sediment concentrations (Tables 29 and 32), contamination factors (Tables 30 and 33), and C_I (Tables 31 and 34) for western and eastern shore tributaries, respectively.

TABLE 15. LEVELS OF CHROMIUM (mg/kg) IN OYSTER TISSUE IN VIRGINIA (SOURCE: GILINSKY AND ROLAND 1983)

James River Area	Mean	Minimum Value	Maximum Value	N
Tidal Fresh Segment	-	-	-	0
River Estuarine Transition	-	-	-	0
Lower Estuary				
LE-5 upper	4.40	3.00	5.80	2
LE-5 lower	4.00	4.00	4.00	2
Elizabeth River	3.5	3.50	3.50	2
Lynnhaven Bay	2.55	2.50	2.60	2
Back River	-	-	-	0
Mouth of Chesapeake Bay	-	-	-	0
Total of James River	3.6	2.50	5.80	8
York River Area				
River Estuarine Transition	3.75	2.50	5.00	2
Lower Estuary	3.40	3.0	3.80	2
Poquoson River	-	-	-	0
Mobjack Bay	-	-	-	0
Total For York River	3.6	2.50	5.00	4
Rappahannock River				
Tidal Fresh Segment	-	-	-	0
River Estuarine Transition				
RET-3 upper	-	-	-	0
RET-3 lower	4.45	3.00	5.90	2
Lower Estuary				
LE-3 upper	-	-	-	0
LE-3 lower	-	-	-	10
Total for Rappahannock River	4.45	3.00	5.90	12

TABLE 16. LEVELS OF CADMIUM (mg/kg) IN OYSTER TISSUE IN VIRGINIA (SOURCE: GILINSKY AND ROLAND 1983)

James River Area	Mean	Minimum Value	Maximum Value	N
River Estuarine Transition	0.17	0.10	0.20	9
Lower Estuary				
LE-5 upper	1.76	0.10	4.80	137
LE-5 lower	1.22	0.20	4.10	221
Elizabeth River	1.58	0.10	3.00	56
Lynnhaven Bay	0.35	0.18	0.60	19
Back River	0.62	0.11	1.75	32
Mouth of Chesapeake Bay	2.23	1.20	3.60	14
Total of James River	1.13	0.10	4.80	488
York River Area				
River Estuarine Transition	1.39	0.52	3.00	64
Lower Estuary	1.92	0.15	120.0	160
Poquoson River	0.57	0.21	1.00	33
Mobjack Bay	0.23	0.01	0.82	74
Total For York River	1.02	0.01	120.0	331
Rappahannock River				
River Estuarine Transition				
RET-3 upper	0.71	0.05	1.30	20
RET-3 lower	0.77	0.32	1.51	72
Lower Estuary				
LE-3 upper	0.45	0.11	0.73	40
LE-3 lower	0.59	0.11	1.14	98
Total for Rappahannock River	0.63	0.05	1.30	230

TABLE 17. LEVELS OF COPPER (mg/kg) IN OYSTER TISSUE IN VIRGINIA (SOURCE: GILINSKY AND ROLAND 1983)

	Mean	Minimum Value	Maximum Value	N
James River Area				
River Estuarine Transition	3.00	2.5	3.8	9
Lower Estuary				
LE-5 upper	144.39	2.2	240.	137
LE-5 lower	84.21	3.00	272.0	225
Elizabeth River	94.09	3.40	243.00	56
Lynnhaven Bay	8.07	4.4	16.0	20
Back River	18.06	6.60	40.7	32
Mouth of Chesapeake Bay	20.72	14.00	36.0	14
Total of James River	53.22	2.2	272.0	493
York River Area				
River Estuarine Transition	72.56	15.1	137.0	61
Lower Estuary	38.87	2.9	491.0	168
Poquoson River	24.22	13.6	44.0	33
Mobjack Bay	9.77	1.2	75.0	74
Total For York River	36.4	1.2	491.0	336
Rappahannock River				
River Estuarine Transition				
RET-3 upper	24.04	1.8	48.0	20
RET-3 lower	28.86	1.4	65.0	70
Lower Estuary				
LE-3 upper	12.16	2.1	21.9	40
LE-3 lower	16.95	1.8	55.1	104
Total for Rappahannock River	20.5	1.4	65.0	234

TABLE 18. LEVELS OF ZINC (mg/kg) IN OYSTER TISSUE IN VIRGINIA
(SOURCE: GILINSKY AND ROLAND 1983)

James River Area	Mean	Minimum Value	Maximum Value	N
River Estuarine Transition	16	12	19	9
Lower Estuary				
LE-5 upper	1208	11	6000	130
LE-5 lower	993	72	6546	227
Elizabeth River	3563	484	19900	54
Lynnhaven Bay	405	235	600	20
Back River	484	189	829	32
Mouth of Chesapeake Bay	563	435	740	13
Total of James River	1033	11	19900	476
York River Area				
River Estuarine Transition	874	157	1550	61
Lower Estuary	575	102	1550	158
Poquoson River	575	352	920	33
Mobjack Bay	311	52	920	57
Total For York River	583.8	52	1550	309
Rappahannock River				
River Estuarine Transition				
RET-3 upper	336	11	985	20
RET-3 lower	439	123	895	72
Lower Estuary				
LE-3 upper	344	157	548	41
LE-3 lower	425	175	973	107
Total for Rappahannock River	386	11	985	240

TABLE 19. MEAN LEVELS OF PESTICIDES, POLYCHLORINATED BIPHENYLS (PCB'S), AND METALS IN OYSTERS IN VIRGINIA (GILINSKY AND ROLAND 1983)

		Oyster Tissue (ppm)		
Area	Substance	N	Geometric Mean	Range
James River	DDT	212	0.03	0.000 - 0.4
	DDE	318	0.05	0.002 - 0.9
	DDD	308	0.07	0.002 - 1.1
	PCB	20	0.50	0.01 - 2.8
	Cd	488	1.13	0.10 - 4.8
	Cu	493	53.22	2.2 - 272
	Zn	476	1033.00	11 - 19900
York River	DDT	22	0.01	0.001 - 0.04
	DDE	43	0.01	0.001 - 0.09
	DDD	40	0.01	0.002 - 0.03
	PCB	6	0.23	0.04 - 0.40
	Cd	331	1.02	0.01 - 120
	Cr	4	3.6	2.5 - 5.00
	Cu	336	36.4	1.2 - 491
	Zn	309	583.8	52 - 1550
Rappahannock River	DDT	40	0.01	0.001 - 0.03
	DDE	77	0.01	0.001 - 0.02
	DDD	75	0.01	0.002 - 0.06
	Cd	230	0.63	0.05 - 1.3
	Cr	12	4.45	3.0 - 5.9
	Cu	234	20.5	1.4 - 65.0
	Zn	240	386	11 - 985

TABLE 20. MEAN LEVELS OF PESTICIDES AND POLYCHLORINATED BIPHENYLS (PCB'S) IN OYSTERS IN MARYLAND (EISENBERG AND TOPPING 1981)

			Oyster Tissue (ppm)	
Area	Substance	N	Mean	Range
Tolchester-Rockhall	PCB	4	0.013	0.002 - 0.030
	Chlordane	4	0.013	0.008 - 0.020
	DDD	4	0.003	0.002 - 0.004
	DDE	4	0.004	0.002 - 0.005
	Dieldrin	4	0.001	0.001 - 0.001
West Chesapeake (Balto. Harbor to Rhode River)	PCB	36	0.015	0.004 - 0.04
	Chlordane	36	0.015	0.004 - 0.05
	DDD	36	0.003	0.001 - 0.006
	DDE	36	0.003	0.001 - 0.006
	Dieldrin	36	0.002	0.001 - 0.003
Chester River	PCB	12	0.009	0.003 - 0.020
	Chlordane	12	0.010	0.002 - 0.030
	DDD	12	0.002	0.001 - 0.002
	DDE	12	0.003	0.001 - 0.004
	Dieldrin	12	0.002	0.001 - 0.002
West Chesapeake	PCB	7	0.008	0.005 - 0.010
	Chlordane	7	0.006	0.003 - 0.010
	DDD	7	0.002	0.002 - 0.002
	DDE	7	0.002	0.001 - 0.004
	Dieldrin	7	0.001	0.001 - 0.001
East Chesapeake (Kent Island)	PCB	2	0.020	0.020 - 0.020
	Chlordane	2	0.011	0.001 - 0.020
	DDD	2	0.004	0.003 - 0.004
	DDE	2	0.006	0.004 - 0.008
	Dieldrin	2	0.003	0.002 - 0.004
West Chesapeake (Calvert Co.)	PCB	3	0.008	0.005 - 0.010
	Chlordane	3	0.008	0.005 - 0.010
	DDD	3	0.002	0.002 - 0.002
	DDE	3	0.002	0.001 - 0.003
	Dieldrin	3	0.002	0.001 - 0.003
Eastern Bay and Tributaries	PCB	91	0.011	0.003 - 0.020
	Chlordane	91	0.013	0.001 - 0.070
	DDD	91	0.002	0.001 - 0.006
	DDE	91	0.003	0.001 - 0.005
	Dieldrin	91	0.003	0.001 - 0.010

(continued)

TABLE 20. (continued)

Area	Substance	N	Mean	Range
	Oyster Tissue (ppm)			
Patuxent River and Confluence	PCB	23	0.011	0.005 - 0.020
	Chlordane	23	0.009	0.002 - 0.020
	DDD	23	0.002	0.001 - 0.003
	DDE	23	0.002	0.001 - 0.004
	Dieldrin	23	0.002	0.001 - 0.003
East Chesapeake (Choptank River)	PCB	76	0.007	0.001 - 0.020
	Chlordane	76	0.010	0.001 - 0.030
	DDD	76	0.002	0.001 - 0.003
	DDE	76	0.003	0.001 - 0.005
	Dieldrin	76	0.002	0.001 - 0.004
West Chesapeake (lower Potomac River)	PCB	16	0.008	0.001 - 0.020
	Chlordane	16	0.009	0.004 - 0.020
	DDD	16	0.002	0.001 - 0.004
	DDE	16	0.002	0.001 - 0.004
	Dieldrin	16	0.002	0.001 - 0.003
Upper Potomac River	PCB	23	0.013	0.003 - 0.040
	Chlordane	23	0.013	0.002 - 0.030
	DDD	23	0.003	0.001 - 0.005
	DDE	23	0.003	0.001 - 0.006
	Dieldrin	23	0.002	0.001 - 0.003
East Chesapeake (Honga, Nanticoke and Wicomico Rivers, Fishing Bay)	PCB	40	0.005	0.002 - 0.010
	Chlordane	40	0.007	0.001 - 0.030
	DDD	40	0.002	0.001 - 0.003
	DDE	40	0.002	0.001 - 0.007
	Dieldrin	40	0.002	0.001 - 0.002
Tangier Sound	PCB	3	0.004	0.002 - 0.005
	Chlordane	3	0.004	0.003 - 0.007
	DDE	3	0.002	0.001 - 0.002
Tangier Sound (Pocomoke River Pocomoke Sound, Big and Little Annamessex Rivers)	PCB	40	0.004	0.001 - 0.009
	Chlordane	40	0.006	0.002 - 0.030
	DDD	40	0.002	0.001 - 0.004
	DDE	40	0.002	0.001 - 0.005
	Dieldrin	40	0.002	0.001 - 0.003

TABLE 21. MEAN LEVELS OF METALS IN OYSTERS IN MARYLAND (EISENBERG AND TOPPING 1981)

			Oyster Tissue (ppm)	
Area	Metal	N	Geometric Mean	Range
Upper Main Bay	As	38	0.006	0.00 - 0.16
	Cd	58	2.10	0.28 - 5.72
	Cr	55	0.18	0.00 - 1.80
	Cu	58	58.79	6.79 - 274.73
	Hg	58	0.01	0.003 - 0.04
	Pb	54	0.03	0.00 - 0.40
	Zn	58	1280.21	18.70 - 2994.0
Middle Main Bay	As	69	0.148	0.0 - 1.00
	Cd	118	1.42	0.15 - 5.55
	Cr	104	0.13	0.0 - 2.30
	Cu	118	35.13	4.90 - 134.72
	Hg	118	0.02	0.003 - 0.16
	Pb	105	0.19	0.0 - 1.90
	Zn	118	1178.59	22.10 - 9434.00
Patuxent River	As	40	0.13	0.0 - 0.68
	Cd	91	2.20	0.07 - 7.80
	Cr	90	0.08	0.0 - 2.40
	Cu	91	57.86	0.81 - 2494.00
	Hg	91	0.02	0.002 - 0.19
	Pb	89	0.007	0.0 - 0.10
	Zn	91	932.04	7.85 - 2416.00
Potomac River	As	27	0.70	0.00 - 1.20
	Cd	40	0.73	0.16 - 2.21
	Cr	40	0.03	0.00 - 1.00
	Cu	40	16.82	4.17 - 36.10
	Hg	40	0.02	0.002 - 0.23
	Pb	38	0.00	0.00 - 0.00
	Zn	40	575.22	72.20 - 1090.00
Lower Eastern Shore	As	35	0.04	0.00 - 0.87
	Cd	50	0.81	0.06 - 1.67
	Cr	44	0.21	0.00 - 0.90
	Cu	50	27.53	8.21 - 85.44
	Hg	50	0.04	0.004 - 0.23
	Pb	43	0.02	0.00 - 0.50
	Zn	50	1148.88	15.00 - 6025.00

(continued)

TABLE 21. (continued)

			Oyster Tissue (ppm)	
Area	Metal	N	Geometric Mean	Range
Upper Eastern Shore	As	97	0.08	0.00 - 0.93
	Cd	129	1.23	0.08 - 3.85
	Cr	129	0.14	0.00 - 2.70
	Cu	129	28.37	1.70 - 111.80
	Hg	129	0.01	0.001 - 0.17
	Pb	127	0.04	0.00 - 1.60
	Zn	129	802.61	11.40 - 7998.00
Middle Eastern Shore	As	61	0.08	0.00 - 0.82
	Cd	108	1.14	0.14 - 2.42
	Cr	103	0.20	0.00 - 2.40
	Cu	108	30.57	3.22 - 78.70
	Hg	108	0.02	0.002 - 0.05
	Pb	101	0.06	0.00 - 1.40
	Zn	108	886.86	16.00 - 7914.0
Western Tributaries	As	11	0.00	0.00 - 0.00
	Cd	25	1.24	0.15 - 3.53
	Cr	19	0.01	0.00 - 0.10
	Cu	25	36.98	2.62 - 104.93
	Hg	24	0.08	0.002 - 0.26
	Pb	21	0.02	0.00 - 0.40
	Zn	25	835.03	14.59 - 2204.50

TABLE 22. CONCENTRATIONS OF DISSOLVED METALS BY CBP SEGMENTS. N IS NUMBER OF SAMPLES. DATA FROM KINGSTON ET AL. 1982

Segment		N	Mean	Range
		Dissolved Cadmium, ug L^{-1}		
CB-2, 3 Upper Bay	Surface	7	0.039	0.007 - 0.101
	Bottom	7	0.046	0.007 - 0.086
CB-4, 5 Mid-Bay	Surface	29	0.028	0.007 - 0.087
	Bottom	29	0.023	0.007 - 0.022
CB-6, 7, 8 Lower Bay	Surface	15	0.006	0.007 - 0.034
	Bottom	15	0.006	0.007 - 0.040
		Dissolved Chromium, ug L^{-1}		
CB-1, 2, 3 Upper Bay	Surface	7	0.260	0.17 - 0.41
	Bottom	7	0.240	0.11 - 0.40
CB-4, 5 Mid-Bay	Surface	29	0.134	0.00 - 0.74
	Bottom	29	0.209	0.00 - 1.68
CB-6, 7, 8 Lower Bay	Surface	15	0.071	0.00 - 0.14
	Bottom	15	0.161	0.00 - 0.92
		Dissolved Cobalt, ug L^{-1}		
CB-1, 2, 3 Upper Bay	Surface	7	0.081	0.025 - 0.156
	Bottom	7	0.052	0.026 - 0.082
CB-4, 5 Mid-Bay	Surface	29	0.039	0.024 - 0.210
	Bottom	29	0.101	0.017 - 0.556
CB-6, 7, 8 Lower Bay	Surface	15	0.047	0.016 - 0.098
	Bottom	15	0.064	0.025 - 0.144

(continued)

TABLE 22. (continued)

Segment		N	Mean	Range
		Dissolved Copper, ug L^{-1}		
CB-1, 2, 3 Upper Bay	Surface	7	1.01	0.37 - 1.64
	Bottom	7	0.95	0.43 - 1.48
CB-4, 5 Central Bay	Surface	29	0.28	0.08 - 1.14
	Bottom	29	0.17	0.08 - 0.57
CB-6, 7, 8 Lower Bay	Surface	15	0.55	0.08 - 1.80
	Bottom	15	0.35	0.17 - 1.14
		Dissolved Lead, ug L^{-1}		
CB-1, 2, 3 Upper Bay	Surface	7	0.14	0.00 - 0.51
	Bottom	7	0.12	0.00 - 0.40
CB-4, 5 Central Bay	Surface	29	0.11	0.00 - 0.88
	Bottom	29	0.09	0.00 - 0.52
CB-6, 7, 8 Lower Bay	Surface	15	0.09	0.00 - 0.41
	Bottom	15	0.17	0.00 - 1.59
		Dissolved Nickel, ug L^{-1}		
CB-1, 2, 3 Upper Bay	Surface	7	1.47	0.85 - 2.59
	Bottom	7	1.39	0.92 - 1.65
CB-4, 5 Central Bay	Surface	29	1.37	0.56 - 2.30
	Bottom	29	1.23	0.82 - 1.99
CB-6, 7, 8 Lower Bay	Surface	15	1.02	0.78 - 1.32
	Bottom	15	0.90	0.55 - 1.25
		Dissolved Zinc, ug L^{-1}		
CB-1, 2, 3 Upper Bay	Surface	7	1.63	0.00 - 8.09
	Bottom	7	1.43	0.00 - 5.52
CB-4, 5 Central Bay	Surface	29	1.55	0.00 -11.11
	Bottom	29	0.47	0.00 - 2.64
CB-6, 7, 8 Lower Bay	Surface	15	1.49	0.00 - 7.96
	Bottom	15	0.54	0.00 - 1.36

TABLE 23. CONCENTRATIONS OF PARTICULATE METALS BY CBP SEGMENT. N IS THE NUMBER OF SAMPLES. DATA FROM KINGSTON ET AL. 1982

Particulate Cadmium, ug L^{-1}

Segment		N	Mean	Range
CB-2, 3, and ET-2,	Surface	7	0.024	0.003 - 0.059
	Bottom	7	0.046	0.009 - 0.099
CB-4,5	Surface	29	0.007	0.001 - 0.110
	Bottom	29	0.005	0.001 - 0.023
CB-6,7,8	Surface	15	0.001	0.001 - 0.001
Particulate Chromium, ug L^{-1}				
CB-2,3, and ET-2	Surface	7	3.03	0.99 - 4.91
	Bottom	7	3.28	0.95 - 3.01
CB-4,5	Surface	29	0.17	0.00 - 1.71
	Bottom	29	0.29	0.00 - 1.71
CB-6,7,8	Surface	15	0.37	0.01 - 1.46
	Bottom	15	0.57	0.14 - 1.42
Particulate Cobalt, ug L^{-1}				
CB-2,3, and ET-2	Surface	7	1.097	0.381 - 2.365
	Bottom	7	1.234	0.391 - 2.365
CB-4,5	Surface	29	0.058	0.021 - 0.329
	Bottom	29	0.091	0.017 - 0.442
CB-6,7,8	Surface	15	0.080	0.029 - 0.329
	Bottom	15	0.168	0.061 - 1.049
Particulate Copper, ug L^{-1}				
CB-2,3, and ET-2	Surface	7	1.13	0.32 - 2.34
	Bottom	7	1.40	0.95 - 3.34
CB-4,5	Surface	29	0.03	0.00 - 0.44
	Bottom	29	0.09	0.00 - 0.42
CB-6,7,8	Surface	15	0.11	0.00 - 0.74
	Bottom	15	0.28	0.00 - 2.82

(continued)

TABLE 23. (continued)

Segment		N	Mean	Range
		Particulate Lead, ug L^{-1}		
CB-2,3,and ET-2	Surface	7	2.42	0.64 - 4.70
	Bottom	7	3.70	0.63 - 7.30
CB-4,5	Surface	29	0.18	0.01 - 0.68
	Bottom	29	0.33	0.01 - 0.93
CB-6,7,8	Surface	15	0.22	0.01 - 0.90
	Bottom	15	0.26	0.03 - 0.70
		Particulate Nickel, ug L^{-1}		
CB-2,3, and ET-2	Surface	7	1.89	0.73 - 3.90
	Bottom	7	2.30	0.77 - 5.00
CB-4,5	Surface	29	0.26	0.11 - 0.64
	Bottom	29	0.38	0.08 - 1.10
CB-6,7,8	Surface	15	0.22	0.03 - 0.95
	Bottom	15	0.24	0.24 - 1.50
		Particulate Zinc, ug L^{-1}		
CB-2,3,and ET-2	Surface	7	7.85	2.77 - 15.52
	Bottom	7	8.72	3.39 - 14.0
CB-4,5	Surface	28	0.64	0.04 - 2.36
	Bottom	28	0.86	0.07 - 4.00
CB-6,7,8	Surface	15	0.22	0.30 - 4.82
	Bottom	15	0.24	0.40 - 14.9

TABLE 24. CONCENTRATIONS OF PARTICULATE METALS BY CBP SEGMENT. DATA FROM NICHOLS ET AL. 1981; RANGE IS THE MINIMUM AND MAXIMUM VALUES FROM FIVE SURVEYS BETWEEN MARCH-SEPTEMBER 1979, 1980. N IS NUMBER OF VALUES AVERAGED

Segment		N	Mean	Range
			Particulate Cadmium, ug L^{-1}	
CB-2, 3, and ET-2	Surface	20	0.13	0.004 - 1.80
	Bottom	20	0.14	0.013 - 1.80
CB-4,5 Central Bay	Surface	25	0.17	0.004 - 1.20
	Bottom	25	0.11	0.004 - 0.74
CB-6,7,8 Lower Bay	Surface	45	0.18	0.02 - 0.32
	Bottom	45	0.14	0.01 - 0.85
			Particulate Copper, ug L^{-1}	
CB-2, 3, and ET-2	Surface	20	1.89	0.19 - 4.30
	Bottom	20	4.30	0.73 - 17.0
CB-4,5 Central Bay	Surface	25	1.26	0.23 - 3.40
	Bottom	25	1.34	0.80 - 2.90
CB-6,7,8 Lower Bay	Surface	45	0.60	0.13 - 1.50
	Bottom	45	1.48	0.29 - 10.0
			Particulate Lead, ug L^{-1}	
CB-2, 3, and ET-2	Surface	20	2.92	0.50 - 7.80
	Bottom	20	5.50	0.93 - 15.0
CB-4,5 Central Bay	Surface	25	1.18	0.10 - 2.20
	Bottom	25	1.00	0.27 - 3.00
CB-6,7,8 Lower Bay	Surface	45	1.03	0.10 - 4.50
	Bottom	45	1.17	0.40 - 3.40

(continued)

TABLE 24. (continued)

Segment		N	Mean	Range
			Particulate Nickel, ug L^{-1}	
CB-2, 3, and ET-2	Surface	20	1.80	0.16 - 7.10
	Bottom	20	6.21	0.58 - 34.0
CB-4,5 Central Bay	Surface	25	0.89	0.06 - 5.10
	Bottom	25	1.28	0.12 - 6.30
CB-6,7,8 Lower Bay	Surface	45	1.44	0.06 - 2.70
	Bottom	45	1.70	0.07 - 12.0
			Particulate Zinc, ug L^{-1}	
CB-2, 3, and ET-2	Surface	20	12.4	1.70 - 30.0
	Bottom	20	23.8	1.80 - 94.0
CB-4,5 Central Bay	Surface	25	5.0	0.78 - 17.0
	Bottom	25	6.9	0.70 - 24.0
CB-6,7,8 Lower Bay	Surface	45	6.47	0.65 - 28.0
	Bottom	45	11.9	2.1 - 80.0

TABLE 25. BOTTOM SEDIMENT CONCENTRATION OF METALS, GEOMETRIC MEAN, MINIMUM, AND MAXIMUM, OF METALS, IN ug g^{-1} (PPM) BY SEGMENT

	Cd	Cr	Cu	Pb	Ni	Zn	Hg	As
				Geometric Mean				
Upper Bay	2	39	33	41	47	226	1	4
CB-1	1	21	17	16	31	101		2*
CB-2	1	35*	33	41	45	216	1	4
CB-3	2	61	42	60	56	294		5
Mid-Bay	1	28	16	18	20	97	1	6
CB-4	2	36	22	23	27	155		6
CB-5	1	21	11	13	15	57	1	4
Lower Bay	2	9	6	12	7	26	1	4
CB-6	1	11	9	16	10	36	1	4*
CB-7	1	8	6	11	6	24	1	4*
CB-8	4	9	6	10	7	21	1	4*
				Minimum				
Upper Bay	0	4	0	6	11	26	0	.7
CB-1	0	7	0	6	11	45		1.1
CB-2	0	13	4	10	12	41	0	1
CB-3	0	4	2	8	19	26		7
Mid-Bay	0	1	0	1	0	0		1
CB-4	0	4	0	0	2	11		3
CB-5	0	1	0	1	0	0	0	1
Lower Bay	0	.7	.4	1	.4	1	0	1
CB-6	0	2	1	2	2	8	0	2
CB-7	0	.7	.4	1	.4	1	0	1
CB-8	0	2	1	2	1	3	0	2
				Maximum				
Upper Bay	2	159	182	190	150	1000	.3	11
CB-1	2	51	95	53	71	380		1.3
CB-2	2	50	56	72	81	710	.3	6
CB-3	2	159	182	190	150	1000		11
Mid-Bay	4	120	64	108	70	400	.3	15
CB-4	2	120	64	79	70	570		7
CB-5	4	58	40	108	40	240	.3	15
Lower Bay	3200	37	36	49	37	260	.8	11
CB-6	.4	31	36	49	37	260	.8	5
CB-7	.5	37	10	49	21	31	.7	11
CB-8	3200	37	27	39	25	132	.3	4

* Fewer than 10 observations.

TABLE 26. C_f MEAN, MINIMUM, AND MAXIMUM OF METALS BY SEGMENT

	Cd	Cr	Cu	Pb	Ni	Zn
			C_f Mean			
Upper Bay	6	-0.5	2	2	0.4	1
CB-1	3	-0.7	1	0.1	-0.05	0.1
CB-2	4	-0.6*	2	2	0.3	1
CB-3	7	-0.2	3	3	0.7	2
Mid-Bay	5	-0.6	1	0.8	-0.3	-0.5
CB-4	5	-0.4	2	1	-0.1	1
CB-5	4	-0.7	0.2	0.2	-0.5	-0.3
Lower Bay	1548	-1	-0.6	-0.2	-0.8	-1
CB-6	-0.3	-0.9	-0.3	0.2	-0.7	-0.7
CB-7	-0.4	-0.8	-0.7	-0.2	-0.9	-0.9
CB-8	4520	-1	-0.6	-0.4	-0.7	-1
			Minimum			
Upper Bay	-1	-1	-1	-0.6	-0.7	-0.8
CB-1	-1	-1	-1	-0.6	-0.7	-0.6
CB-2	-1	-0.9	-0.7	-0.4	-0.7	-0.6
CB-3	-1	-1	-0.9	-0.5	-0.5	-0.8
Mid-Bay	-1	-1	-1	-1	-1	-2
CB-4	-1	-1	-1	-1	-1	-1
CB-5	-1	-1	-1	-1	-1	-2
Lower Bay	-1	-3	-2	-2	-2	-3
CB-6	-1	-1	-1	-1	-1	-3
CB-7	-1	-2	-2	-1	-2	-3
CB-8	-1	-3	-2	-2	-1	-3
			Maximum			
Upper Bay	19	0.8	14	10	3	8
CB-1	19	-0.4	7	2	1	2
CB-2	15	-0.4	4	3	1	5
CB-3	19	0.8	14	10	3	8
Mid-Bay	42	0.4	4	5	1	4
CB-4	17	0.4	4	4	1	4
CB-5	42	-0.3	2	5	0.1	1
Lower Bay	96,996	-0.6	2	3	0.03	1
CB-6	13	-0.5	2	3	0.03	1
CB-7	4	-0.6	0.6	2	0.4	-1
CB-8	96,996	-0.5	1	1	-3	0.2

* Less than 10 observations.

TABLE 27. C_I MEAN, MINIMUM, AND MAXIMUM BY SEGMENT

	Mean	Minimum	Maximum
Upper Bay	12.5	-5	49
CB-1	4.9	-5	31
CB-2	13.1*	-2.1	22
CB-3	19.2	0.8	49
Mid-Bay	6.2	-6	46
CB-4	9.0	-5.5	26
CB-5	2.5	-6	46
Lower Bay	-4	-6	7.2
CB-6	-3.9	-5.6	- 0.5
CB-7	-4.2	-6	2.6
CB-8	-3.9	-6	7

* Less than 10 observations.

TABLE 28. MEAN CONCENTRATIONS OF TOTAL METAL IN CBP SEGMENTS. N IS THE NUMBER OF SAMPLES. DATA FROM VIRGINIA STATE '106' PROGRAM. METAL CONTENT IN ug/L^{-1}

Segment	Mean	Range	N	Mean	Range	N	Mean	Range	N
POTOMAC	Cadmium			Chromium			Copper		
TF-2	3.7	1-10	4	12.2	10-20	9	19.3	10-50	15
RET-2									
LE-2				16.4	10-40	22	24.7	10-70	17
	Lead			Nickel			Zinc		
TF-2	13.2	1-90	44	20	10-30	2	38.6	10-440	57
RET-2	6.5	3-10	4				25.0	10-40	8
LE-2	11.1	2-60	34				22.5	3-90	24
RAPPAHANNOCK	Cadmium			Chromium			Copper		
TF-3				12.5	10-20	4	16.0	10-30	5
RET-3				11.8	10-20	11	24.0	10-80	24
LE-3	5.0	.03-10	2	14.3	10-30	49	29.0	.03-80	83
	Lead			Nickel			Zinc		
TF-3	9.1	6-12	7				44.4	10-110	9
RET-3	28.0	1-30	10				59.0	10-230	31
LE-3	13.6	1-60	86				54.6	.02-470	84
YORK	Cadmium			Chromium			Copper		
TF-4	20.0	20-20	4	10.5	10-20	21	14.8	10-30	33
RET-4	22.5	10-30	4	15.6	10-40	18	20.5	10-40	36
LE-4	10.6	1-20	9	19.4	10-40	62	28.9	10-90	67
WE-4	10.0		1	15.4	10-30	24	30.6	10-60	34
	Lead			Nickel			Zinc		
TF-4	11.7	2-126	74				37.2	0-710	280
RET-4	18.6	1-110	41				37.9	10-480	53
LE-4	17.9	1-80	80				25.7	3-130	74
WE-4	17.4	1-70	41				60.0	10-460	26

(continued)

TABLE 28. (continued)

Segment	Mean	Range	N	Mean	Range	N	Mean	Range	N
JAMES	Cadmium			Chromium			Copper		
TF-5	10.0	10-10	5	18.6	10-90	59	22.0	10-110	61
RET-5	10		1	14.0	10-30	10	20.7	10-50	15
LE-5	151.9	1-1319	16	15.4	10-100	267	30.1	10-200	330
	Lead			Nickel			Zinc		
TF-5	24.3	1-735	114				86.8	10-1589	112
RET-5	9.7	3-20					51.1	10-460	27
LE-5	13.4	0.6-140	487				57.6	10-3399	423

TABLE 29. BOTTOM SEDIMENT GEOMETRIC MEAN, MINIMUM, AND MAXIMUM OF METALS ug g^{-1} (WESTERN SHORE)

	Cd	Cr	Cu	Pb	Ni	Zn	Hg	As
			Geometric Mean					
Western Tributaries	3	253	156	171	43	471	1*	4*
WT-1								
WT-2			65		58	277		
WT-3			80*			75*	380*	
WT-4	5		156	382		681		
WT-5	3	258	174	161	42	493	1*	4*
WT-6								
WT-7								
WT-8	1 *	66 *	17 *	12 *	7 *	112 *		
Patuxent	1 *	24 *	16 *	17 *	14 *	75 *		
TF-1								
RET-1								
LE-1	1 *	24 *	16 *	17 *	14 *	75 *		
			Minimum					
Western Tributaries	.2	0	6	5	6	31	0	1
WT-1								
WT-2			45		34	200		
WT-3			57		59	360		
WT-4	2		86	130		338		
WT-5	.2	0	10	5	12	31	0	1
WT-6								
WT-7								
WT-8	0.3		6			46		
Patuxent	0.3	4	3	3	3	12		
TF-1								
RET-1								
LE-1	0.1	4	3	3	3	12		
			Maximum					
Western Tributaries	654	4756	2926	13890	190	5500	0.4	8
WT-1								
WT-2			96		73	360		
WT-3			110		92	400		
WT-4	5		230	640		936		
WT-5	654	4756	2926	13890	190	5500	0.4	8
WT-6								
WT-7								
WT-8	0.7		123			232		

* Less than 10 observations.

(continued)

TABLE 29. (Continued)

	Cd	Cr	Cu	Pb	Ni	Zn	Hg	Ag	As
				Maximum (continued)					
Patuxent	0.7	58	36	40	30	210			
TF-1									
RET-1									
LE-1	0.7	58	36	40	30	210			
				Geometric Mean					
Potomac	1	28	25	36	21	202	1*		4
TF-2	2	33	29	44	24	211	1*		4
RET-2		31*	28*	28*	25*	325*			
LE-2	1*	19	17	23	15	128			
Rappahannock	3*	21	15	22	20	73	1*		11*
TF-3									
RET-3									
LE-3	3*	21	15	22*	20	73			11*
York	2*	28	15	25	13	78	1		12*
TF-4		58*	36*	42*	23*	227*	1*		8*
RET-4	4*	46	29	40	19	172	1		13*
LE-4	2*	20	11	15	10	59	1		10*
James	3	34	6	34	16	188	1	2*	7
TF-5	3	16	20	23	12	118	1		5
RET-5	1*	4*	27	34	2*	149	1		3*
LE-5	3	38	26	36	18	217	1	2	8
				Minimum					
Potomac	0	2	0	4	0	0	0		0
TF-2	0	10	4	10	8	37	0		0
RET-2		21	14	5	15	158			
LE-2	0	2	0	4	0	0			
Rappahannock	0.2	2	0.6	1	3	4	0.1		1
TF-3									
RET-3									
LE-3	0.2	2	0.6	0.1	3	4			1
York	0.02	2	1	1	1	4	0.03		7
TF-4		36	30	33	10	184	0.2		
RET-4	3.3	11	6	11	7	52	0.06		7
LE-4	0.03	3	1	3	2	9	0.03		7
James	0	1	0.4	0.2	0.7	0.4	0	1	.2
TF-5	0.2	3	2	0.2	1	16	0.005		.2
RET-5	0	1	1	0.5	1	4	0		1
LE-5	0	1	0.4	0.3	1	0.4	0	1	1

(continued)

TABLE 29. (Continued)

	Cd	Cr	Cu	Pb	Ni	Zn	Hg	Ag	As
				Maximum					
Potomac	10	76	64	450	67	1062	0.2		8
TF-2	10	76	64	450	48	910	0.2		8
RET-2		44	50	107	36	1062			
LE-2	0.7	51	50	59	67	894			
Rappahannock	8	45	32	75	30	148	0.3		15
TF-3									
RET-3									
LE-3	8	45	32	0.3	30	148			15
York	3	133	50	88	36	327	1.4		19
TF-4		90	50	50	36	313	0.9		
RET-4	3.4	133	47	88	30	327	1.4		19
LE-4	2	67	28	38	29	207	0.4		13
James	26	207	336	563	54	7750	2.7	2	42
TF-5	4	49	151	72	54	2000	1		16
RET-5	0.3	7	336	53	4	393	2		4
LE-5	26	207	246	563	45	7750	3	42	42

* Less than 10 observations.

TABLE 30. C_f MEAN, MINIMUM, AND MAXIMUM OF METALS (WESTERN SHORE)

	Cd	Cr	Cu	Pb	Ni	Zn
			C_f Mean			
Western Tributaries	62	5	24	18	0.2	5
WT-1						
WT-2			5		0.6	2
WT-3			6 *		1 *	2 *
WT-4	42		12	23		5
WT-5	64	5	27	19	0.1	6
WT-6						
WT-7						
WT-8	5 *	-0.6*	4 *	-0.3*	-0.8*	-0.02*
Patuxent	4 *	-0.6*	0.8*	0.4*	-0.5*	0.1*
TF-1						
RET-1						
LE-1	4 *	-0.6*	0.8*	0.4*	-0.5*	0.1*
Mobjack						
WE-4	-0.2*	-1 *	0.2	1	-1 *	-0.7
			Minimum			
Western Tributaries	1	-1	-1	-0.7	-0.8	-1
WT-1						
WT-2			3		-0.1	0.8
WT-3						
WT-4	21		6	7		2
WT-5	1	-1	-0.2	-0.7	-0.7	-0.7
WT-6						
WT-7						
WT-8						
Patuxent	0.1	0.1	-0.8	-0.8	-0.9	-0.9
TF-1						
RET-1						
LE-1	0.1	-1	-0.8	-0.8	-1	-0.9
Mobjack						
WE-4	-0.8	-1	-1	-1	-1	-2

(continued)

TABLE 30. (Continued)

	Cd	Cr	Cu	Pb	Ni	Zn
			Maximum			
Western Tributaries	6539	53	242	816	4	49
WT-1						
WT-2			7.		1	2
WT-3						
WT-4	52		18	37		8
WT-5	6539	54	243	816	4	49
WT-6						
WT-7						
WT-8						
Patuxent	6	-0.3	2	1	-0.2	0.9
TF-1						
RET-1						
LE-1	6	-0.3	2	1.4	-0.2	0.9
Mobjack						
WE-4	1	-0.8	3	5	-0.7	-0.1

* Less than 10 observations.

(continued)

TABLE 30. (Continued)

	Cd	Cr	Cu	Pb	Ni	Zn
			C_f Mean			
Potomac	10	-1	2	3	-0.5	3
TF-2	15 *	-1	3	5	-0.6	3
RET-2		-1 *	2 *	2 *	-0.5*	4 *
LE-2	3 *	-0.9	1	0.8	-0.5	2
Rappahannock	30 *	-1 *	0.8*	1.*	-0.5*	-0.1*
TF-3						
RET-3						
LE-3	30	-1	0.8	1	-0.5	-0.1
York	9.*	-1	1	2	-1	-0.05
TF-4		-1 *	5 *	4 *	-1 *	3 *
RET-4	33.*	-1 *	4 *	5 *	-1 *	2 *
LE-4	6.*	-2 *	0.001*	0.1*	-2 *	-0.8*
James	49.	-1 *	4	4	-1 *	5
TF-5	18.	-2	2	1	-1	1
RET-5	1.*	-1 *	2	1	-1 *	0.7
LE-5	56.	-1	5	6	-1	9
			Minimum			
Potomac	-2.	-2	-1	-0.8	-2	-0.6
TF-2	-2.	-2	-0.3	-0.2	-1	-0.7
RET-2		-1	0.4	-0.7	-0.6	0.4
LE-2	-1.	-2	-1	-0.7	-2	-1
Rappahannock	.8	-2	-0.4	-0.6	-1	-0.8
TF-3						
RET-3						
LE-3	0.8	-2	-0.4	-0.6	-1	-0.8
York	-0.8	-2	-1	-1	-3.	-2
TF-4						
RET-4		-1	1	2	-2.	0.4
LE-4	-0.7	-2	-1	-1	-3.	-2
James	-1	-3	-3	-2	-3.	-3
TF-5	1	-3	-2	-1	-3.	-2
RET-5	-1	-2	-1.5	-1	-2.	-2
LE-5	-1	2.9	-2.7	-1.6	-2.6	-2.5

(continued)

TABLE 30. (Continued)

	Cd	Cr	Cu	Pb	Ni	Zn
				Maximum		
Potomac	99	-0.4	6	25	0.9	10
TF-2	99	-0.4	6	25	0.05	8
RET-2		-0.6	4	5	-0.4	10
LE-2	6	-0.4	3	2	0.9	7
Rappahannock	83	-0.5	3	4	-0.2	0.3
TF-3						
RET-3						
LE-3	83	-0.5	3	4	-0.2	0.3
York	33	0.2	7	8	-0.4	4
TF-4						
RET-4		-2	7	8	-0.8	4
LE-4	17	-0.8	1	2	-0.7	0.4
James	646	3	79	111	0.04	490
TF-5	39	-1	41	11	0.04	17
RET-5	3	-1	58	28	-1	16
LE-5	646	2.6	79	111	-0.2	490

* Less than 10 observations.

TABLE 31. C_I MEAN, MINIMUM, AND MAXIMUM (WESTERN SHORE)

	C_I Mean	Minimum	Maximum
Western Tributaries	133	0.02	6850
WT-1			
WT-2			
WT-3			
WT-4			
WT-5	134	7	6850
WT-6			
WT-7			
WT-8	0.02*		
Patuxent	4.1*	-4	10
TF-1			
RET-1			
LE-1	4.1*	-4	10
Potomac	10.4	-6	32
TF-2	15.3*	-0.8	32
RET-2			
LE-2	4.8*	-6	16
Rappahannock	31.0*	-2.4	79
TF-3			
RET-3			
LE-3	31.0*	-2.4	79
York	7.5*	-5	42
WE-4	-4.3*	-5	-1
RET-4	39.*	36	42
LE-4	2.3*	-5	14
James	69	-6	362
TF-5	12.3*	-0.2	26
RET-5	-4.2*		
LE-5	76	-6	362

* Less than 10 observations.

TABLE 32. BOTTOM SEDIMENT GEOMETRIC MEAN, MINIMUM, AND MAXIMUM OF METALS (EASTERN SHORE)

	Cd	Cr	Cu	Pb	Ni	Zn
			Geometric Mean			
Upper Eastern Shore	2	22	11	20	50 *	79
ET-1	3 *	58 *	74 *	56.*	84 *	341 *
ET-2						
ET-3						
ET-4	2	19	9	19		70
Mid Eastern Shore	2 *	25 *	11 *	13.*	15 *	123 *
EE-1	2 *	23 *	8 *	22.*	9 *	124 *
EE-2	1.*	32 *	26 *	3.*	24 *	121 *
ET-5						
			Minimum			
Upper Eastern Shore	0.1	2	0.7	2		7
ET-1						
ET-2						
ET-3						
ET-4	0.1	2	0.7	2		7
Mid-Eastern Shore	0.5	8	0	2	8	50
EE-1	0.8	8	0	6		50
EE-2						
ET-5						
			Maximum			
Upper Eastern Shore	2	110	73	58		340
ET-1						
ET-2						
ET-3						
ET-4	2	110	26	58		307
Mid-Eastern Shore	1	39	25	43	23	206
EE-1	1	39	23	43		206
EE-2						
ET-5						

* Less than 10 observations.

(continued)

TABLE 32. (Continued)

	Cd	Cr	Cu	Pb	Ni	Zn
			Geometric Mean			
Lower Eastern Shore	1	10	8	19		54
ET-6						
ET-7	1	9	8	19		52
ET-8						
ET-9						
ET-10						
ET-11						
EE-3	1.1*	27 *	13 *	17 *		66 *
			Minimum			
Lower Eastern Shore	0.1	1.5	1	2		6
ET-6						
ET-7	0.1	2	1	2		6
ET-8						
ET-9						
ET-10						
ET-11						
EE-3						
			Maximum			
Lower Eastern Shore	5	20	29	88		330
ET-6						
ET-7	5	20	29	88		330
ET-8						
ET-9						
ET-10						
ET-11						
EE-3						

* Less than 10 observations.

TABLE 33. C_f MEAN, MINIMUM, AND MAXIMUM OF METALS (EASTERN SHORE)

	Cd	Cr	Cu	Pb	Ni	Zn
			C_f Mean			
Upper Eastern Shore	8	-0.7	0.3	0.7	1 *	0.1
ET-1	19 *	0.3*	5 *	2 *	1 *	2 *
ET-2						
ET-3						
ET-4	8	-0.7	-0.03	0.6		-0.03
Mid-Eastern Shore	7 *	-0.7*	0.4*	0.3*	-0.6*	0.3*
EE-1	9	-0.7	0.2	0.7	-0.8*	0.3
EE-2	4 *	-0.6*	1 *	-0.9*	-0.4*	0.1*
ET-5						
			Minimum			
Upper Eastern Shore	0.2	-1	-1	-0.9		-0.9
ET-1						
ET-2						
ET-3						
ET-4	0.2	-1	-1	-0.9		-1
Mid-Eastern Shore	4	-1	-1	-0.9		-0.5
EE-1	7	-0.9	-1	-0.7		-0.5
EE-2						
ET-5						
			Maximum			
Upper Eastern Shore	20	0.3	5	2		2
ET-1						
ET-2						
ET-3						
ET-4	20	0.3	1	2		2
Mid-Eastern Shore	10	-0.6	1	2		0.9
EE-1	10	-0.6	0.9	2		0.9
EE-2						
ET-5						

* Less than 10 observations.

(continued)

TABLE 33. (Continued)

	Cd	Cr	Cu	Pb	Ni	Zn
				C_f Mean		
Lower Eastern Shore	13	-0.9	-0.1	0.4	-1.*	-0.3
ET-6						
ET-7	5	-0.9	-0.2	0.5		-0.3
ET-8						
ET-9						
ET-10						
ET-11						
EE-3		-0.9*	-0.3*	-0.06*	-1.*	-0.6*
				Minimum		
Lower Eastern Shore	0	-1	-1	-0.9		-1
ET-6						
ET-7	0	-1	-1	-0.9		-1
ET-8						
ET-9						
ET-10						
ET-11						
EE-3						
				Maximum		
Lower Eastern Shore	49	-0.7	1	4		2
ET-6						
ET-7	49	-0.8	1	4		0.6
ET-8						
ET-9						
ET-10						
ET-11						
EE-3						

* Less than 10 observations.

TABLE 34. C_I MEAN, MINIMUM, AND MAXIMUM (EASTERN SHORE)

	C_I Mean	Minimum	Maximum
Upper Eastern Shore	29.4*		
ET-1	29.4*		
ET-2			
ET-3			
ET-4			
Mid-Eastern Shore	4.4*	2.8	6.1
EE-1	6.1*		
EE-2	2.8*		
ET-5			
Lower Eastern Shore	-2.8*		
ET-6			
ET-7			
ET-8			
ET-9			
ET-10			
ET-11			
EE-3	-2.8*		

* Less than 10 observations

SECTION 8

CURRENT CONDITIONS AND TRENDS

The physical and chemical variables described in this section were used to characterize segments of Chesapeake Bay. They include: salinity, temperature, pH, turbidity, nutrients (forms of phosphorus and nitrogen), dissolved oxygen (DO), chlorophyll a.

The data are presented as a series of tables grouped by physical variables and nutrient variables. Statistics for each year's annual mean will be presented for the years 1977 to 1980 (Table 35a-d); seasonal means for each variable will then be shown, by year, for years 1977 to 1980 (Table 36a-d). The same arrangement is followed for nutrients (Tables 37a-d and 38a-d).

Summary of physical and nutrient means (depth-averaged) for current conditions (1977 to 1980) are based on criterion requiring:

$\geq$ 3 observations/segment for monthly mean;
$\geq$ 2 monthly means/segment for seasonal mean;
$\geq$ 2 seasonal means/segment for annual mean.

Monthly means, number of observations, standard deviation, minimum, and maximum values are available for use in hard copy at the CBP office, Annapolis, MD; an example is shown in Table 39. All of the above variables are also available for top ($<$ 10 m) and bottom ($\geq$10 m) level in hard copy.

Statistically significant trends over time in nutrients for each segment are summarized in Table 40 (annual trends) and Table 41 (seasonal trends). Table 41 is further subdivided into 41a (spring), 41b (summer), 41c (fall), and 41d (winter). An analysis of these trends is included in Chapter 1, Section 2. The actual distribution of nutrient data (grouped by 7 1/2 - minute USGS quadrangles) is shown in Figures 40 through 47.

TABLE 35a. SUMMARY STATISTICS FOR PHYSICAL MEANS ANNUAL DATA

SEGMENT	YEAR	LEVEL	TEMP	SALIN	PH	SECCHI	JTU
CB-1	1977	T	16.2	.	7.7	.	.
CB-2	1977	T	17.5	1.30	7.5	0.55	17.45
CB-3	1977	T	18.7	6.78	7.7	0.75	12.52
CB-3	1977	B	16.7	12.82	.	.	.
CB-4	1977	T	17.9	11.61	7.9	1.81	4.19
CB-4	1977	B	14.8	17.21	7.9	.	.
CB-5	1977	T	17.1	13.52	7.6	.	.
WT-2	1977	T	17.9	.	7.8	.	11.27
WT-5	1977	T	15.9	.	.	.	.
WT-6	1977	T	19.3	7.54	.	0.81	7.35
WT-8	1977	T	19.7	9.41	7.9	.	6.57
TF-1	1977	T	18.6	2.85	7.1	.	48.81
TF-2	1977	T	20.7	0.51	7.7	0.61	31.67
RET-2	1977	T	20.6	6.27	7.2	.	18.86
LE-2	1977	T	20.1	.	6.9	.	15.23
TF-3	1977	T	22.6	2.38	.	0.62	.
TF-3	1977	B	22.8	.	.	.	.
RET-3	1977	T	21.7	8.31	.	0.65	.
LE-3	1977	T	21.1	15.61	.	1.26	.
TF-4	1977	T	25.0	3.84	.	0.58	.
RET-4	1977	T	22.2	10.26	.	0.59	.
LE-4	1977	T	21.4	18.79	.	0.85	.
LE-4	1977	B	21.0	.	.	.	.
TF-5	1977	T	24.6	2.06	.	0.63	.
RET-5	1977	T	23.8	.	.	.	.
LE-5	1977	T	22.9	18.26	.	1.06	.
LE-5	1977	B	20.9	.	.	.	.
ET-2	1977	T	20.3	.	7.5	.	54.23
ET-4	1977	T	19.0	5.35	7.6	.	30.88
ET-5	1977	T	19.6	.	7.3	.	11.94
ET-6	1977	T	21.9	.	7.4	.	18.90
ET-7	1977	T	20.1	.	7.5	.	19.43
ET-10	1977	T	21.0	.	6.5	.	14.77
EE-1	1977	T	18.9	10.72	7.8	.	.
EE-3	1977	T	20.1	10.96	7.1	.	18.31
WE-4	1977	T	21.2	.	.	.	.

TABLE 35b. SUMMARY STATISTICS FOR PHYSICAL MEANS ANNUAL DATA

SEGMENT	YEAR	LEVEL	TEMP	SALIN	PH	SECCHI	JTU
CB-1	1978	T	23.8	.	7.9	.	6.83
CB-2	1978	T	18.2	1.56	7.9	0.59	25.61
CB-3	1978	T	16.8	6.54	7.8	0.74	13.76
CB-4	1978	T	17.8	10.76	8.0	1.81	4.43
CB-4	1978	B	16.5	16.39	7.3	.	3.27
CB-5	1978	T	17.5	12.42	8.0	.	2.49
CB-5	1978	B	21.5	17.00	7.6	.	.
WT-5	1978	T	17.5	7.13	7.5	.	9.77
TF-1	1978	T	18.3	1.07	7.0	0.53	23.74
RET-1	1978	T	19.4	7.69	7.4	.	24.40
LE-1	1978	T	19.2	10.11	7.8	.	5.72
TF-2	1978	T	19.9	0.21	7.8	0.56	12.12
TF-2	1978	B	21.3	0.19	7.8	.	.
RET-2	1978	T	20.9	3.23	7.6	0.60	17.90
TF-3	1978	T	19.1	.	.	0.54	.
TF-3	1978	B	19.5	.	.	.	.
RET-3	1978	T	19.4	7.02	.	0.50	.
LE-3	1978	T	20.3	.	.	.	.
TF-4	1978	T	22.8	2.69	.	0.51	.
RET-4	1978	T	23.1	6.91	.	0.46	.
LE-4	1978	T	22.9	.	.	.	.
LE-4	1978	B	22.5	18.67	.	.	.
TF-5	1978	T	20.4	.	.	0.56	.
TF-5	1978	B	23.6	.	.	.	.
RET-5	1978	T	20.0	.	.	.	.
LE-5	1978	T	19.9	6.58	.	.	.

TABLE 35c. SUMMARY STATISTICS FOR PHYSICAL MEANS ANNUAL DATA

SEGMENT	YEAR	LEVEL	TEMP	SALIN	PH	SECCHI	JTU
CB-1	1979	T	20.5	.	.	.	9.46
CB-2	1979	T	17.8	.	7.7	0.52	22.28
CB-3	1979	T	14.9	7.34	7.8	0.74	11.21
CB-3	1979	B	16.5	11.09	.	.	.
CB-4	1979	T	18.5	9.15	7.9	1.54	4.28
CB-5	1979	T	16.3	13.24	8.2	.	4.24
WT-5	1979	T	14.7	5.50	7.6	.	12.67
TF-2	1979	T	17.4	0.46	7.6	0.48	22.16
TF-2	1979	B	16.0	.	7.5	.	.
RET-2	1979	T	17.6	1.64	7.6	0.49	25.26
RET-2	1979	B	15.0	.	7.5	.	.
RET-3	1979	T	20.3	3.30	.	0.44	.
LE-3	1979	T	22.0	.	8.0	.	.
LE-3	1979	B	19.8	.	.	.	.
RET-4	1979	T	21.6	5.18	.	.	.
LE-4	1979	T	21.8	10.67	.	.	.
LE-4	1979	B	21.6	.	.	.	.
TF-5	1979	T	16.9	.	.	0.54	.
TF-5	1979	B	21.5	.	.	.	.
RET-5	1979	T	17.0	.	.	.	.
RET-5	1979	B	20.2	.	.	.	.
LE-5	1979	T	17.4	7.46	.	0.57	.
LE-5	1979	B	20.5	.	.	.	.

TABLE 35d. SUMMARY STATISTICS FOR PHYSICAL MEANS ANNUAL DATA

SEGMENT	YEAR	LEVEL	TEMP	SALIN	PH	SECCHI	JTU
CB-1	1980	T	19.0	.	7.6	.	11.87
CB-2	1960	T	19.1	0.80	7.7	0.60	16.17
CB-3	1980	T	14.1	10.16	7.6	1.17	7.71
CB-4	1980	T	16.9	11.31	8.0	1.50	4.44
CB-4	1980	B	15.0	17.74	7.5	.	5.44
CB-5	1980	T	.	.	.	.	2.76
WT-4	1980	T	16.1	.	.	.	.
WT-5	1980	T	14.4	7.01	7.7	.	8.95
TF-1	1980	T	21.1	4.86	7.3	0.17	.
LE-1	1980	T	21.8	14.52	7.7	.	.
TF-2	1980	T	20.9	0.14	7.3	.	20.78
TF-2	1980	B	19.7	0.11	7.2	.	.
RET-2	1980	T	19.8	2.93	7.5	.	11.52
LE-3	1980	T	16.7	.	7.7	.	.
ET-4	1980	T	18.5	8.26	.	1.88	.

TABLE 36a. SUMMARY STATISTICS FOR PHYSICAL MEANS SEASONAL DATA

SEGMENT	YEAR	SEASON	LEVEL	TEMP	SALIN	PH	SECCHI	JTU
CB-1	1977	SPRING	T	8.7	.	7.4	.	.
CB-1	1977	SUMMER	T	25.9	0.15	8.0	.	.
CB-1	1977	FALL	T	14.0	.	.	.	7.09
CB-2	1977	SPRING	T	13.0	.	7.7	0.54	18.31
CB-2	1977	SUMMER	T	25.8	1.53	7.7	0.58	12.89
CB-2	1977	FALL	T	13.6	1.07	7.2	0.52	21.14
CB-3	1977	SPRING	T	14.1	3.99	7.6	0.66	15.08
CB-3	1977	SPRING	B	10.3	11.82	7.4	.	.
CB-3	1977	SUMMER	T	25.2	7.63	7.6	0.78	8.53
CB-3	1977	SUMMER	B	23.0	13.81	.	.	.
CB-3	1977	FALL	T	16.7	8.72	7.8	0.80	13.95
CB-4	1977	SPRING	T	12.8	8.50	8.0	1.35	5.17
CB-4	1977	SPRING	B	6.0	15.98	7.8	.	.
CB-4	1977	SUMMER	T	25.0	12.22	8.0	1.56	4.11
CB-4	1977	SUMMER	B	20.9	18.03	7.9	.	.
CB-4	1977	FALL	T	16.0	14.11	7.7	2.51	3.28
CB-4	1977	FALL	B	17.5	17.63	.	.	3.41
CB-5	1977	SPRING	T	8.8	12.14	8.1	.	.
CB-5	1977	SUMMER	T	23.9	14.12	7.6	.	.
CB-5	1977	FALL	T	18.5	14.30	7.2	2.59	.
CB-5	1977	FALL	B	18.4	16.50	.	.	.
WT-1	1977	SUMMER	T	23.1	.	7.9	.	.
WT-2	1977	SPRING	T	12.7	.	7.5	.	13.54
WT-2	1977	SUMMER	T	23.0	0.11	8.1	.	9.00
WT-4	1977	SPRING	T	13.3	0.73	7.8	.	88.33
WT-5	1977	SPRING	T	13.4	.	.	.	.
WT-5	1977	SUMMER	T	24.0	.	.	.	15.78
WT-5	1977	FALL	T	10.3	10.34	.	.	.
WT-6	1977	SPRING	T	14.7	5.01	.	0.83	8.22
WT-6	1977	SUMMER	T	24.1	9.05	8.1	0.73	7.46
WT-6	1977	FALL	T	19.2	8.55	.	0.88	6.37
WT-7	1977	SUMMER	T	23.8	9.82	8.2	.	5.72
WT-8	1977	SPRING	T	11.6	5.93	8.1	.	7.82
WT-8	1977	SUMMER	T	25.2	10.63	7.7	.	6.56
WT-8	1977	FALL	T	22.2	11.66	7.8	.	5.33
TF-1	1977	SPRING	T	13.8	.	7.3	.	63.26
TF-1	1977	SUMMER	T	24.2	3.44	6.9	.	34.36
TF-1	1977	FALL	B	17.8	1.16	.	.	.
RET-1	1977	FALL	T	18.7	11.14	7.6	0.78	.
LE-1	1977	FALL	T	18.9	13.25	.	.	.
LE-1	1977	FALL	B	15.7	13.77	.	.	.

(continued)

TABLE 36a. (Continued)

SEGMENT	YEAR	SEASON	LEVEL	TEMP	SALIN	PH	SECCHI	JTU
TF-2	1977	SPRING	T	16.7	0.13	7.7	0.56	28.70
TF-2	1977	SPRING	B	18.2	0.13	.	.	.
TF-2	1977	SUMMER	T	26.5	0.26	7.7	0.59	34.63
TF-2	1977	FALL	T	18.8	1.14	.	0.68	.
RET-2	1977	SPRING	T	18.0	3.14	7.5	.	10.14
RET-2	1977	SUMMER	T	25.1	5.54	6.8	0.50	27.57
RET-2	1977	FALL	T	18.8	10.12	.	.	.
LE-2	1977	SPRING	T	15.6	.	7.0	.	8.17
LE-2	1977	SUMMER	T	24.5	.	6.7	.	22.29
TF-3	1977	SPRING	T	19.5	.	.	0.53	.
TF-3	1977	SPRING	B	19.7	.	.	.	.
TF-3	1977	SUMMER	T	26.7	1.34	.	0.52	.
TF-3	1977	SUMMER	B	25.9	.	.	.	.
TF-3	1977	FALL	T	21.5	3.42	.	0.80	.
RET-3	1977	SPRING	T	18.6	4.62	.	0.40	.
RET-3	1977	SUMMER	T	25.0	8.55	.	0.44	.
RET-3	1977	FALL	T	21.4	11.77	.	1.10	.
LE-3	1977	SPRING	T	17.1	13.29	.	1.00	.
LE-3	1977	SUMMER	T	25.0	15.30	.	1.14	.
LE-3	1977	SUMMER	B	25.2	.	.	.	.
LE-3	1977	FALL	T	21.2	18.25	.	1.63	.
TF-4	1977	SUMMER	T	26.6	2.72	.	0.53	.
TF-4	1977	FALL	T	23.4	4.96	.	0.62	.
RET-4	1977	SPRING	T	16.9	6.12	.	.	.
RET-4	1977	SUMMER	T	26.4	10.64	.	0.54	.
RET-4	1977	FALL	T	23.2	14.02	.	0.64	.
LE-4	1977	SPRING	T	15.1	15.02	.	0.71	.
LE-4	1977	SPRING	B	14.7	.	.	.	.
LE-4	1977	SUMMER	T	25.9	19.61	.	0.86	.
LE-4	1977	SUMMER	B	24.8	.	.	.	.
LE-4	1977	FALL	T	23.2	21.74	.	0.99	.
LE-4	1977	FALL	B	23.4	.	.	.	.
TF-5	1977	SUMMER	T	28.8	1.42	.	0.58	.
TF-5	1977	SUMMER	B	28.1	.	.	.	.
TF-5	1977	FALL	T	20.4	2.70	.	0.67	.
RET-5	1977	SUMMER	T	27.5	.	.	.	.
RET-5	1977	FALL	T	20.0	.	.	.	.
LE-5	1977	SUMMER	T	26.0	17.48	.	0.91	.
LE-5	1977	FALL	T	19.8	19.03	.	1.21	.
LE-5	1977	FALL	B	19.5	23.58	.	.	.
ET-2	1977	SPRING	T	15.0	.	7.4	.	78.80
ET-2	1977	SUMMER	T	25.6	0.97	7.5	.	29.65
ET-3	1977	SUMMER	T	26.7	0.24	8.1	.	13.17

(continued)

TABLE 36a. (Continued)

SEGMENT	YEAR	SEASON	LEVEL	TEMP	SALIN	PH	SECCHI	JTU
ET-4	1977	SPRING	T	11.9	3.96	7.7	.	26.06
ET-4	1977	SUMMER	T	26.1	6.74	7.5	.	35.69
ET-5	1977	SPRING	T	13.9	.	7.1	.	11.77
ET-5	1977	SUMMER	T	25.2	3.44	7.5	.	12.11
ET-6	1977	SPRING	T	16.9	.	7.7	.	21.59
ET-6	1977	SUMMER	T	26.9	2.47	7.1	.	16.20
ET-7	1977	SPRING	T	14.7	.	7.6	.	27.08
ET-7	1977	SUMMER	T	25.4	5.07	7.4	.	11.78
ET-10	1977	SPRING	T	16.4	.	6.2	.	16.60
ET-10	1977	SUMMER	T	25.5	6.06	6.8	.	12.94
EE-1	1977	SPRING	T	11.7	9.90	8.0	2.26	.
EE-1	1977	SUMMER	T	26.0	11.54	7.5	.	4.92
EE-3	1977	SPRING	T	13.7	10.22	7.1	.	21.88
EE-3	1977	SUMMER	T	26.4	11.69	7.1	.	14.73
WE-4	1977	SPRING	T	14.9	.	.	.	.
WE-4	1977	SUMMER	T	25.6	.	.	.	.
WE-4	1977	FALL	T	23.0	.	.	.	.
WE-4	1977	FALL	B	22.7	.	.	.	.

TABLE 36b. SUMMARY STATISTICS FOR PHYSICAL MEANS SEASONAL DATA

SEGMENT	YEAR	SEASON	LEVEL	TEMP	SALIN	PH	SECCHI	JTU
CB-1	1978	SUMMER	T	25.6	0.14	7.4	.	6.51
CB-1	1978	FALL	T	21.9	.	8.4	.	7.15
CB-2	1978	SPRING	T	7.1	.	7.6	0.50	36.75
CB-2	1978	SUMMER	T	26.2	0.52	7.9	0.67	13.79
CB-2	1978	FALL	T	21.4	2.59	8.2	.	26.28
CB-3	1978	SPRING	T	7.6	3.57	7.9	0.48	22.26
CB-3	1978	SPRING	B	5.2	11.01	7.6	.	.
CB-3	1978	SUMMER	T	24.4	5.35	7.6	0.84	8.87
CB-3	1978	FALL	T	18.3	10.69	7.9	0.91	10.15
CB-4	1978	SPRING	T	6.5	9.52	7.9	2.29	6.99
CB-4	1978	SPRING	B	5.1	14.54	7.2	.	.
CB-4	1978	SUMMER	T	24.5	9.18	8.0	1.62	3.21
CB-4	1978	SUMMER	B	21.7	15.18	7.1	.	3.20
CB-4	1978	FALL	T	22.5	13.58	8.1	1.53	3.10
CB-4	1978	FALL	B	22.7	19.45	7.5	.	3.33
CB-5	1978	SPRING	T	9.1	10.03	7.9	.	2.59
CB-5	1978	SUMMER	T	24.4	10.91	8.1	1.83	2.59
CB-5	1978	SUMMER	B	23.0	14.55	7.5	.	.
CB-5	1978	FALL	T	19.1	16.31	8.0	.	2.28
CB-5	1978	FALL	B	20.0	19.44	7.7	.	2.59
WT-2	1978	SUMMER	T	26.4	.	8.3	.	.
WT-5	1978	SPRING	T	10.5	.	.	.	.
WT-5	1978	SUMMER	T	23.5	4.51	7.5	.	8.84
WT-5	1978	FALL	T	18.6	9.74	7.4	.	10.70
TF-1	1978	SPRING	T	14.9	0.71	6.9	0.54	26.43
TF-1	1978	SUMMER	T	24.5	0.89	7.0	0.43	26.08
TF-1	1978	SUMMER	B	25.3	.	7.0	.	38.63
TF-1	1978	FALL	T	15.5	1.62	7.1	0.62	18.70
RET-1	1978	SPRING	T	14.7	4.97	7.6	.	20.95
RET-1	1978	SUMMER	T	25.4	6.55	7.3	0.50	20.42
RET-1	1978	FALL	T	18.1	11.56	7.4	.	31.82
LE-1	1978	SPRING	T	13.4	7.58	8.0	.	5.80
LE-1	1978	SUMMER	T	24.7	8.91	7.6	.	8.59
LE-1	1978	SUMMER	B	23.4	10.95	7.1	.	.
LE-1	1978	FALL	T	19.4	13.83	7.7	.	2.78
TF-2	1978	SPRING	T	13.9	0.12	7.7	0.51	13.79
TF-2	1978	SPRING	B	17.9	.	.	.	.
TF-2	1978	SUMMER	T	26.6	0.20	7.8	0.58	12.05
TF-2	1978	SUMMER	B	26.9	0.15	7.5	.	.
TF-2	1978	FALL	B	19.0	0.23	8.0	.	.
RET-2	1978	SPRING	T	16.8	1.26	7.3	0.40	24.93
RET-2	1978	SPRING	B	16.4	.	7.2	.	.
RET-2	1978	SUMMER	T	26.4	2.35	7.6	0.55	18.43
RET-2	1978	FALL	T	19.6	6.09	7.9	0.84	10.35

(continued)

TABLE 36b. (Continued)

SEGMENT	YEAR	SEASON	LEVEL	TEMP	SALIN	PH	SECCHI	JTU
TF-3	1978	SUMMER	T	25.4	0.17	.	0.34	.
TF-3	1978	SUMMER	B	26.0	.	.	.	.
TF-3	1978	FALL	T	12.8	.	.	0.73	.
TF-3	1978	FALL	B	13.0	.	.	.	.
RET-3	1978	SUMMER	T	25.1	4.85	.	0.31	.
RET-3	1978	FALL	T	13.6	9.18	.	0.68	.
LE-3	1978	SUMMER	T	24.6	12.36	.	1.15	.
LE-3	1978	SUMMER	B	24.4	13.54	.	.	.
LE-3	1978	FALL	T	15.9	.	.	.	.
TF-4	1978	SUMMER	T	24.1	1.97	.	0.45	.
TF-4	1978	FALL	T	21.5	3.40	.	0.57	.
RET-4	1978	SUMMER	T	25.1	5.86	.	0.39	.
RET-4	1978	FALL	T	21.1	7.95	.	0.53	.
LE-4	1978	SUMMER	T	25.2	16.08	.	0.75	.
LE-4	1978	SUMMER	B	24.3	18.78	.	.	.
LE-4	1978	FALL	T	20.5	.	.	.	.
LE-4	1978	FALL	B	20.7	18.56	.	.	.
TF-5	1978	SPRING	T	15.3	.	.	.	.
TF-5	1978	SUMMER	T	28.1	.	.	0.47	.
TF-5	1978	SUMMER	B	27.1	.	.	.	.
TF-5	1978	FALL	T	17.8	.	.	0.65	.
TF-5	1978	FALL	B	20.1	.	.	.	.
RET-5	1978	SPRING	T	14.8	.	.	.	.
RET-5	1978	SUMMER	T	27.1	.	.	.	.
RET-5	1978	SUMMER	B	27.3	.	.	.	.
RET-5	1978	FALL	T	18.2	.	.	.	.
LE-5	1978	SPRING	T	14.6	4.51	.	.	.
LE-5	1978	SUMMER	T	26.9	8.65	.	.	.
LE-5	1978	SUMMER	B	20.9	.	.	.	.
LE-5	1978	FALL	T	18.3	.	.	.	.
ET-5	1978	SUMMER	T	25.6	.	7.0	.	.
ET-10	1978	SPRING	T	15.1	.	.	.	.
*E-4	1978	SUMMER	T	23.7	.	.	.	.

TABLE 36c. SUMMARY STATISTICS FOR PHYSICAL MEANS SEASONAL DATA

SEGMENT	YEAR	SEASON	LEVEL	TEMP	SALIN	PH	SECCHI	JTU
CB-1	1979	SUMMER	T	25.2	.	.	0.93	9.47
CB-1	1979	FALL	T	15.8	.	.	.	9.45
CB-2	1979	SPRING	T	14.5	.	7.8	.	28.06
CB-2	1979	SUMMER	T	23.8	0.97	7.6	0.54	19.59
CB-2	1979	FALL	T	15.0	.	.	0.49	19.18
CB-3	1979	SPRING	T	14.8	5.55	7.8	0.66	15.62
CB-3	1979	SPRING	B	12.1	9.69	7.2	.	.
CB-3	1979	SUMMER	T	22.9	6.33	7.6	0.83	8.92
CB-3	1979	SUMMER	B	20.9	12.48	.	.	.
CB-3	1979	FALL	T	15.6	5.60	7.9	0.74	9.09
CB-3	1979	WINTER	T	6.3	11.87	7.9	.	.
CB-4	1979	SPRING	T	15.0	8.98	8.1	1.78	4.31
CB-4	1979	SPRING	B	10.4	16.80	7.4	.	4.75
CB-4	1979	SUMMER	T	22.5	8.76	7.7	1.46	3.96
CB-4	1979	FALL	T	18.0	9.70	.	1.37	4.57
CB-5	1979	SPRING	T	16.3	12.39	8.5	.	2.75
CB-5	1979	SPRING	B	13.3	16.62	7.6	.	.
CB-5	1979	SUMMER	T	23.0	12.30	7.8	.	.
CB-5	1979	FALL	T	19.8	12.28	8.4	.	5.72
CB-5	1979	WINTER	T	6.0	15.98	8.0	.	.
CB-7	1979	SPRING	T	16.8	21.94	8.4	.	.
WT-5	1979	SPRING	T	12.0	4.62	7.2	.	11.08
WT-5	1979	SUMMER	T	23.8	6.20	7.6	.	20.43
WT-5	1979	FALL	T	16.7	5.69	7.9	.	7.10
WT-5	1979	WINTER	T	6.4	.	.	.	.
TF-2	1979	SPRING	T	12.5	0.14	7.5	0.40	24.28
TF-2	1979	SPRING	B	13.3	.	7.4	.	.
TF-2	1979	SUMMER	T	24.6	0.78	7.7	0.52	22.89
TF-2	1979	SUMMER	B	24.4	0.82	7.6	.	.
TF-2	1979	FALL	T	15.0	.	7.7	0.53	19.31
TF-2	1979	FALL	B	10.4	.	7.6	.	.
RET-2	1979	SPRING	T	13.0	1.19	7.6	0.36	35.25
RET-2	1979	SPRING	B	11.5	4.72	7.5	.	.
RET-2	1979	SUMMER	T	24.0	2.30	7.6	0.54	20.64
RET-2	1979	FALL	T	15.7	1.43	7.6	0.58	19.90
RET-2	1979	FALL	B	18.5	.	7.4	.	.
TF-3	1979	SUMMER	T	24.8	.	.	.	.
RET-3	1979	SUMMER	T	24.8	3.30	.	0.38	.
RET-3	1979	FALL	T	15.8	3.29	.	0.49	.
LE-3	1979	SUMMER	B	22.2	.	.	.	.
LE-3	1979	FALL	T	18.8	.	8.5	1.62	.
LE-3	1979	FALL	B	17.4	11.88	.	.	.
TF-4	1979	SUMMER	T	25.9	2.33	.	0.36	.

(continued)

TABLE 36c. (Continued)

SEGMENT	YEAR	SEASON	LEVEL	TEMP	SALIN	PH	SECCHI	JTU
RET-4	1979	SUMMER	T	25.0	6.35	.	0.34	.
RET-4	1979	FALL	T	18.1	4.00	.	.	.
LE-4	1979	SUMMER	T	24.3	9.31	.	0.66	.
LE-4	1979	SUMMER	B	24.2	18.30	.	.	.
LE-4	1979	FALL	T	19.2	12.02	.	.	.
LE-4	1979	FALL	B	18.9	.	.	.	.
TF-5	1979	SPRING	T	16.5	.	.	0.48	.
TF-5	1979	SPRING	B	19.1	.	.	.	.
TF-5	1979	SUMMER	T	27.1	.	.	0.70	.
TF-5	1979	SUMMER	B	25.7	.	.	.	.
TF-5	1979	FALL	T	17.5	.	.	0.63	.
TF-5	1979	FALL	B	19.7	.	.	.	.
TF-5	1979	WINTER	T	6.5	.	.	0.36	.
RET-5	1979	SPRING	T	16.6	.	.	.	.
RET-5	1979	SPRING	B	16.4	.	.	.	.
RET-5	1979	SUMMER	T	26.1	.	.	.	.
RET-5	1979	SUMMER	B	26.0	.	.	.	.
RET-5	1979	FALL	T	18.2	.	.	.	.
RET-5	1979	FALL	B	18.3	.	.	.	.
RET-5	1979	WINTER	T	7.2	.	.	.	.
LE-5	1979	SPRING	T	18.2	.	.	0.45	.
LE-5	1979	SUMMER	T	25.7	8.44	.	0.64	.
LE-5	1979	SUMMER	B	22.8	.	.	.	.
LE-5	1979	FALL	T	17.7	6.11	.	0.63	.
LE-5	1979	FALL	B	18.1	.	.	.	.
LE-5	1979	WINTER	T	7.8	7.84	.	.	.
ET-3	1979	SUMMER	T	24.1	.	.	.	.
ET-5	1979	SUMMER	T	20.9	.	6.5	.	12.36
WE-4	1979	SUMMER	T	25.3	.	.	.	.
WE-4	1979	SUMMER	B	24.9	.	.	.	.

TABLE 36d. SUMMARY STATISTICS FOR PHYSICAL MEANS SEASONAL DATA

SEGMENT	YEAR	SEASON	LEVEL	TEMP	SALIN	PH	SECCHI	JTU
CB-1	1980	SPRING	T	13.7	.	7.2	.	11.47
CB-1	1980	SUMMER	T	24.3	0.11	7.9	.	12.26
CB-2	1980	SPRING	T	14.3	0.08	7.8	0.59	14.02
CB-2	1980	SUMMER	T	23.8	1.52	7.5	0.60	18.32
CB-3	1980	SPRING	T	11.4	5.85	7.5	0.78	11.53
CB-3	1980	SUMMER	T	23.4	9.81	7.6	1.56	3.89
CB-3	1980	SUMMER	B	21.4	11.09	7.4	.	.
CB-3	1980	FALL	T	16.7	14.83	.	.	.
CB-3	1980	WINTER	T	5.0	.	.	.	.
CB-4	1980	SPRING	T	11.7	10.50	8.2	1.44	5.93
CB-4	1980	SPRING	B	9.5	18.67	7.6	.	8.04
CB-4	1980	SUMMER	T	22.0	12.12	7.8	1.55	2.95
CB-4	1980	SUMMER	B	20.5	16.80	7.4	.	2.84
CB-5	1980	SPRING	T	.	.	.	.	3.10
CB-5	1980	SUMMER	T	23.4	13.81	7.6	.	2.42
CB-5	1980	SUMMER	B	21.8	18.88	7.3	.	.
WT-4	1980	SPRING	T	10.2	.	.	.	.
WT-4	1980	SUMMER	T	26.6	.	.	.	.
WT-4	1980	FALL	T	21.4	.	.	.	.
WT-4	1980	WINTER	T	6.0	.	.	.	.
WT-5	1980	SPRING	T	13.1	6.22	7.6	.	11.43
WT-5	1980	SUMMER	T	24.2	7.80	7.7	.	6.47
WT-5	1980	FALL	T	15.2	.	.	.	.
WT-5	1980	WINTER	T	5.1	.	.	.	.
TF-1	1980	SUMMER	T	25.6	3.47	7.2	0.15	.
TF-1	1980	FALL	T	16.6	6.25	7.4	0.18	.
LE-1	1980	SUMMER	T	25.9	13.05	7.5	.	.
LE-1	1980	FALL	T	17.6	15.99	7.8	.	.
TF-2	1980	SPRING	T	14.8	0.08	7.3	.	23.19
TF-2	1980	SPRING	B	14.1	0.08	7.3	.	.
TF-2	1980	SUMMER	T	26.5	0.10	7.3	0.61	18.36
TF-2	1980	SUMMER	B	25.3	0.13	7.0	.	.
TF-2	1980	FALL	T	21.5	0.25	7.4	.	.
RET-2	1980	SPRING	T	14.5	1.21	7.6	.	12.55
RET-2	1980	SUMMER	T	25.0	4.64	7.4	0.63	10.48
RET-2	1980	SUMMER	B	24.2	8.45	7.1	.	.
LE-3	1980	SPRING	T	11.6	.	7.4	.	.
LE-3	1980	SUMMER	T	24.6	.	7.8	.	.
LE-3	1980	FALL	T	13.9	.	8.0	.	.
TF-4	1980	SUMMER	T	26.2	.	.	.	.
TF-5	1980	SUMMER	T	27.2	.	.	0.43	.
RET-5	1980	SUMMER	T	25.9	.	.	0.52	.

(continued)

TABLE 36d. (Continued)

SEGMENT	YEAR	SEASON	LEVEL	TEMP	SALIN	PH	SECCHI	JTU
LE-5	1980	SUMMER	T	24.9	22.31	.	0.96	.
LE-5	1980	SUMMER	B	22.4	26.18	.	.	.
ET-4	1980	SUMMER	T	26.0	6.82	7.5	2.94	10.30
ET-4	1980	FALL	T	11.0	9.70	.	0.82	.
ET-5	1980	SUMMER	T	25.6	3.05	7.0	.	14.01
WE-4	1980	SUMMER	T	25.2	.	.	.	.
WE-4	1980	SUMMER	B	22.4	.	.	.	.

TABLE 37a. SUMMARY STATISTICS FOR NUTRIENT MEANS (MG L^{-1} EXCEPT CHL-AU[1] WHICH IS IN MICROGRAMS PER LITER) (ANNUAL DATA)

SEGMENT	YEAR		LEVEL	TP	IPF	TN	NH3	NO3	NO2	TKN	CHL-AU	D.O.
CB-1	1977	ANNUAL	T	.	.	.	.	.	.	.	.	10.07
CB-2	1977	ANNUAL	T	0.079	0.032	1.059	0.049	0.731	0.015	0.38	15.28	9.41
CB-3	1977	ANNUAL	T	0.078	0.040	0.780	0.097	0.364	0.014	0.40	24.61	8.38
CB-3	1977	ANNUAL	B	.	.	.	.	.	.	.	.	4.69
CB-4	1977	ANNUAL	T	0.064	0.025	0.695	0.054	0.328	0.011	0.41	14.55	8.74
CB-4	1977	ANNUAL	B	.	.	.	.	.	.	.	.	5.78
CB-5	1977	ANNUAL	T	.	.	.	.	.	.	.	.	9.42
WT-2	1977	ANNUAL	T	0.062	.	1.456	0.039	1.180	0.020	0.26	9.85	10.22
WT-5	1977	ANNUAL	T	.	.	.	.	.	.	.	.	9.48
WT-6	1977	ANNUAL	T	0.078	.	0.570	0.067	0.196	0.014	0.36	37.18	8.07
WT-8	1977	ANNUAL	T	0.100	0.050	0.803	0.028	0.205	0.009	0.38	28.70	8.81
TF-1	1977	ANNUAL	T	0.387	0.269	1.928	0.266	1.147	0.094	0.69	32.38	7.01
TF-2	1977	ANNUAL	T	0.105	0.049	1.431	0.232	0.712	0.044	0.63	40.34	7.69
RET-2	1977	ANNUAL	T	0.141	0.105	0.934	0.114	0.397	0.029	0.47	32.91	7.15
LE-2	1977	ANNUAL	T	0.073	0.046	0.515	0.032	0.165	0.010	0.34	12.14	8.32
TF-3	1977	ANNUAL	T	0.160	0.026	.	0.173	.	0.026	0.51	.	7.41
RET-3	1977	ANNUAL	T	0.117	0.026	.	0.121	.	0.014	.	.	7.20
LE-3	1977	ANNUAL	T	0.096	0.021	.	0.076	.	0.010	.	.	6.82
TF-4	1977	ANNUAL	T	0.097	0.019	.	.	.	0.014	0.33	.	5.87
RET-4	1977	ANNUAL	T	0.088	0.031	.	0.102	.	0.017	0.38	.	5.78
LE-4	1977	ANNUAL	T	0.071	0.030	.	0.113	.	0.012	.	.	6.35
LE-4	1977	ANNUAL	B	0.071	0.026	.	.	.	0.010	.	.	5.49
TF-5	1977	ANNUAL	T	.	.	.	.	.	.	0.63	.	6.31
LE-5	1977	ANNUAL	T	.	.	.	.	.	.	.	.	6.80
LE-5	1977	ANNUAL	B	.	.	.	.	.	.	.	.	6.52
ET-2	1977	ANNUAL	T	0.101	0.047	1.229	0.054	0.946	0.012	0.42	38.43	9.11
ET-4	1977	ANNUAL	T	0.126	0.048	0.993	0.116	0.381	0.014	0.60	73.62	8.65
ET-5	1977	ANNUAL	T	0.106	0.064	1.091	0.037	0.790	0.012	0.30	37.94	8.68
ET-6	1977	ANNUAL	T	0.081	0.044	1.066	0.064	0.750	0.015	0.31	36.15	8.36
ET-7	1977	ANNUAL	T	0.132	0.080	1.440	0.292	0.871	0.033	0.54	44.24	8.77
ET-10	1977	ANNUAL	T	0.090	0.059	0.942	0.095	0.531	0.009	0.41	17.72	7.40
EE-1	1977	ANNUAL	T	0.091	0.017	0.589	0.049	0.225	0.008	0.36	20.00	8.78
EE-3	1977	ANNUAL	T	0.064	0.027	0.696	0.064	0.084	0.010	0.61	21.93	7.90

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[1] Chlorophyll a, uncorrected

TABLE 37b. SUMMARY STATISTICS FOR NUTRIENT MEANS (MG L^{-1} EXCEPT CHL-AU[1] WHICH IS IN MICROGRAMS PER LITER) (ANNUAL DATA)

SEGMENT	YEAR		LEVEL	TP	IPF	TN	NH3	NO3	NO2	TKN	CHL-AU	D.O.
CB-1	1978	ANNUAL	T	0.123	0.062	1.551	0.071	0.846	0.058	0.65	.	7.72
CB-2	1978	ANNUAL	T	0.142	0.047	1.169	0.107	0.760	0.022	0.65	29.66	9.89
CB-3	1978	ANNUAL	T	0.164	0.056	1.326	0.121	0.532	0.024	0.81	12.90	9.03
CB-4	1978	ANNUAL	T	0.125	0.039	0.986	0.092	0.309	0.020	0.74	9.77	8.84
CB-4	1978	ANNUAL	B	0.120	0.054	0.856	0.213	0.092	0.033	0.80	6.53	4.27
CB-5	1978	ANNUAL	T	0.127	0.040	0.997	0.077	0.266	0.021	0.72	10.20	8.75
CB-5	1978	ANNUAL	B	.	.	.	.	.	.	.	.	4.02
WT-5	1978	ANNUAL	T	0.134	0.053	1.507	0.515	0.370	0.066	1.11	20.23	7.73
TF-1	1978	ANNUAL	T	0.460	.	2.464	0.329	1.338	0.071	1.05	38.09	7.57
RET-1	1978	ANNUAL	T	0.150	.	1.041	0.101	0.226	0.026	0.79	18.04	6.86
LE-1	1978	ANNUAL	T	0.124	.	0.937	0.091	0.172	0.024	0.76	.	7.46
TF-2	1978	ANNUAL	T	0.161	0.075	1.628	0.220	0.763	0.070	0.84	39.86	8.93
TF-2	1978	ANNUAL	B	.	.	.	.	.	.	.	.	7.14
RET-2	1978	ANNUAL	T	0.152	0.120	0.839	0.068	0.529	0.025	0.49	22.51	7.15
TF-3	1978	ANNUAL	T	0.145	0.038	0.927	0.113	.	.	0.48	.	8.10
RET-3	1978	ANNUAL	T	0.100	0.026	0.556	0.067	.	.	0.46	.	7.66
LE-3	1978	ANNUAL	T	0.051	0.017	.	0.112	.	.	0.54	.	6.93
TF-4	1978	ANNUAL	T	0.148	0.030	.	.	0.070	0.008	0.51	.	6.00
RET-4	1978	ANNUAL	T	0.120	0.030	.	.	0.092	0.017	.	.	5.53
LE-4	1978	ANNUAL	T	0.098	0.033	.	.	0.097	0.041	.	.	5.85
LE-4	1978	ANNUAL	B	0.101	0.034	.	.	0.072	0.042	.	.	4.64
TF-5	1978	ANNUAL	T	0.211	0.128	1.310	0.173	.	.	0.58	.	7.57
TF-5	1978	ANNUAL	B	.	.	.	.	.	.	.	.	6.96
LE-5	1978	ANNUAL	T	0.103	0.043	.	0.130	.	.	0.35	.	7.31

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[1] Chlorophyll a, uncorrected

TABLE 37c. SUMMARY STATISTICS FOR NUTRIENT MEANS (MG L^{-1} EXCEPT CHL-AU[1] WHICH IS IN MICROGRAMS PER LITER) (ANNUAL DATA)

SEGMENT	YEAR		LEVEL	TP	IPF	TN	NH3	NO3	NO2	TKN	CHL-AU	D.O.
CB-1	1979	ANNUAL	T	0.101	.	.	0.062	.	0.036	0.44	17.19	8.56
CB-2	1979	ANNUAL	T	0.148	0.039	1.370	0.058	0.872	0.021	0.49	15.59	8.96
CB-3	1979	ANNUAL	T	0.075	0.036	1.190	0.105	0.338	0.029	0.52	18.28	7.86
CB-4	1979	ANNUAL	T	0.062	0.048	.	0.072	0.240	0.067	0.47	20.10	7.31
CB-5	1979	ANNUAL	T	0.019	0.020	0.927	0.045	0.076	0.048	0.57	10.69	8.42
WT-5	1979	ANNUAL	T	0.076	0.027	2.032	0.308	0.716	0.037	0.97	27.07	8.27
TF-2	1979	ANNUAL	T	0.108	0.052	1.683	0.304	0.822	0.046	0.69	19.50	8.71
TF-2	1979	ANNUAL	B	.	.	.	.	.	.	.	.	8.59
RET-2	1979	ANNUAL	T	0.108	0.054	1.561	0.140	0.837	0.029	0.62	22.56	8.18
RET-2	1979	ANNUAL	B	.	.	.	.	.	.	.	.	7.63
RET-3	1979	ANNUAL	T	.	.	.	.	.	.	.	.	7.46
LE-3	1979	ANNUAL	T	.	.	.	0.035	0.045	0.016	.	.	7.02
LE-3	1979	ANNUAL	B	.	.	.	.	.	.	.	.	5.31
RET-4	1979	ANNUAL	T	.	.	.	.	.	.	.	.	6.37
LE-4	1979	ANNUAL	T	.	.	.	.	.	.	.	.	6.27
LE-4	1979	ANNUAL	B	.	.	.	.	.	.	.	.	5.06
TF-5	1979	ANNUAL	T	0.163	0.074	.	0.207	0.424	.	0.51	.	9.01
TF-5	1979	ANNUAL	B	0.206	0.052	.	0.217	0.555	.	0.80	.	6.99
RET-5	1979	ANNUAL	T	.	.	.	.	.	.	.	.	7.58
LE-5	1979	ANNUAL	T	0.112	0.040	.	0.128	0.431	.	0.42	.	8.47

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[1] Chlorophyll a, uncorrected

TABLE 37d. SUMMARY STATISTICS FOR NUTRIENT MEANS (MG L^{-1} EXCEPT CHL-AU[1] WHICH IS IN MICROGRAMS PER LITER) (ANNUAL DATA)

SEGMENT	YEAR		LEVEL	TP	IPF	TN	NH3	NO3	NO2	TKN	CHL-AU	D.O.
CB-1	1980	ANNUAL	T	0.059	0.016	1.465	0.069	0.949	0.023	0.50	29.75	8.92
CB-2	1980	ANNUAL	T	0.069	0.020	1.395	0.047	0.812	0.013	0.58	29.69	9.04
CB-3	1980	ANNUAL	T	0.061	0.060	1.793	0.248	0.449	0.027	0.96	22.90	9.15
CB-4	1980	ANNUAL	T	0.062	0.027	1.099	0.081	0.286	0.005	0.81	26.00	8.24
CB-4	1980	ANNUAL	B	0.060	0.035	1.000	0.137	0.203	0.005	0.80	13.30	4.80
CB-5	1980	ANNUAL	T	0.042	0.026	0.970	0.062	0.210	0.005	0.76	12.80	.
WT-4	1980	ANNUAL	T	.	.	.	1.916	1.051	0.318	.	.	7.99
WT-5	1980	ANNUAL	T	0.108	0.030	2.084	0.294	0.763	0.020	1.36	33.16	8.12
TF-1	1980	ANNUAL	T	.	.	.	.	.	.	.	30.38	7.62
LE-1	1980	ANNUAL	T	.	.	.	.	.	.	.	12.57	6.84
TF-2	1980	ANNUAL	T	0.099	0.029	1.849	0.359	0.843	0.055	0.89	32.04	8.63
TF-2	1980	ANNUAL	B	.	.	.	.	.	.	.	.	7.94
RET-2	1980	ANNUAL	T	0.111	0.039	1.600	0.107	0.722	0.025	0.77	35.93	8.14
LE-3	1980	ANNUAL	T	.	.	.	0.043	0.022	0.007	.	.	9.76
ET-4	1980	ANNUAL	T	0.225	.	0.833	0.114	0.330	0.061	0.54	.	.

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[1] Chlorophyll a, uncorrected

TABLE 38a. SUMMARY STATISTICS FOR NUTRIENT MEANS (MG L^{-1} EXCEPT CHL-AU[1] WHICH IS IN MICROGRAMS PER LITER) (SEASONAL DATA)

SEGMENT	YEAR	SEASON	LEVEL	TP	IPF	TN	NH3	NO3	NO2	TKN	CHL-AU	D.O.
CB-1	1977	SPRING	T	.	.	.	.	.	.	.	.	12.63
CB-1	1977	SUMMER	T	.	.	.	.	.	.	.	.	7.92
CB-1	1977	FALL	T	0.045	0.027	1.022	0.035	0.707	0.009	0.31	13.00	9.67
CB-2	1977	SPRING	T	0.124	0.031	1.232	0.063	1.087	0.012	0.33	5.75	11.32
CB-2	1977	SUMMER	T	0.053	0.032	0.742	0.064	0.432	0.024	0.30	25.95	6.72
CB-2	1977	FALL	T	0.059	0.032	1.203	0.021	0.673	0.009	0.52	14.14	10.20
CB-3	1977	SPRING	T	0.069	0.040	1.072	0.146	0.677	0.019	0.37	23.15	9.72
CB-3	1977	SPRING	B	.	.	.	.	.	.	.	.	7.19
CB-3	1977	SUMMER	T	0.088	0.035	0.448	0.070	0.045	0.004	0.39	35.71	6.81
CB-3	1977	SUMMER	B	.	.	.	.	.	.	.	.	2.18
CB-3	1977	FALL	T	0.077	0.044	0.820	0.076	0.370	0.018	0.44	14.98	8.62
CB-4	1977	SPRING	T	0.050	0.021	0.915	0.053	0.699	0.015	0.35	15.00	10.50
CB-4	1977	SPRING	B	.	.	.	.	.	.	.	.	9.61
CB-4	1977	SUMMER	T	0.061	0.025	0.381	0.050	0.033	0.004	0.34	18.79	6.77
CB-4	1977	SUMMER	B	.	.	.	.	.	.	.	.	1.60
CB-4	1977	FALL	T	0.082	0.030	0.790	0.058	0.252	0.014	0.53	9.87	8.95
CB-4	1977	FALL	B	0.088	0.036	0.651	0.047	0.178	0.019	0.45	11.00	6.14
CB-5	1977	SPRING	T	.	.	.	.	.	.	.	.	12.17
CB-5	1977	SUMMER	T	.	.	.	.	.	.	.	.	7.46
CB-5	1977	FALL	T	.	.	.	.	.	.	.	.	8.64
CB-5	1977	FALL	B	.	.	.	.	.	.	.	.	7.23
WT-1	1977	SUMMER	T	0.050	0.031	1.199	0.030	0.799	0.016	0.39	29.08	8.46
WT-2	1977	SPRING	T	0.075	.	1.625	0.030	1.375	0.016	0.24	5.68	10.90
WT-2	1977	SUMMER	T	0.049	.	1.287	0.047	0.985	0.024	0.28	14.01	9.54
WT-4	1977	SPRING	T	.	.	.	1.289	1.204	0.059	.	93.54	10.43
WT-5	1977	SPRING	T	.	.	.	.	.	.	.	.	10.12
WT-5	1977	SUMMER	T	0.062	.	0.952	0.034	0.668	0.028	0.26	12.63	8.93
WT-5	1977	FALL	T	.	.	.	.	.	.	.	.	9.38
WT-6	1977	SPRING	T	0.050	.	0.731	0.054	0.410	0.014	0.32	35.79	9.40
WT-6	1977	SUMMER	T	0.090	.	0.446	0.079	0.061	0.007	0.38	35.57	6.52
WT-6	1977	FALL	T	0.093	.	0.532	0.069	0.118	0.021	0.39	40.19	8.29
WT-7	1977	SUMMER	T	0.069	0.031	0.454	0.027	0.047	0.004	0.41	40.75	8.18
WT-8	1977	SPRING	T	0.060	0.028	1.624	0.037	0.521	0.015	0.46	40.01	11.41
WT-8	1977	SUMMER	T	0.125	0.070	0.337	0.019	0.027	0.004	0.31	23.35	7.29
WT-8	1977	FALL	T	0.116	0.052	0.449	0.027	0.066	0.008	0.38	22.73	7.73

(continued)

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[1] Chlorophyll *a*, uncorrected

SEGMENT	YEAR	SEASON	LEVEL	TP	IPF	TN	NH3	NO3	NO2	TKN	CHL-AU	D.O.
TF-1	1977	SPRING	T	0.378	0.241	1.842	0.344	0.965	0.050	0.83	26.00	9.03
TF-1	1977	SUMMER	T	0.395	0.296	2.013	0.187	1.329	0.137	0.55	38.75	5.52
TF-1	1977	FALL	T	.	.	.	.	.	.	.	.	6.48
TF-1	1977	FALL	B	.	.	.	.	.	.	.	.	6.72
RET-1	1977	FALL	T	.	.	.	.	.	.	.	.	7.13
LE-1	1977	FALL	T	.	.	.	.	.	.	.	.	8.16
LE-1	1977	FALL	B	.	.	.	.	.	.	.	.	7.66
TF-2	1977	SPRING	T	0.104	0.062	1.265	0.256	0.677	0.027	0.56	28.65	9.60
TF-2	1977	SPRING	B	.	.	.	.	.	.	.	.	8.13
TF-2	1977	SUMMER	T	0.104	0.053	1.323	0.188	0.644	0.070	0.54	43.44	6.52
TF-2	1977	FALL	T	0.106	0.033	1.704	0.252	0.814	0.034	0.80	48.94	6.95
RET-2	1977	SPRING	T	0.149	0.108	1.116	0.120	0.508	0.020	0.47	33.94	8.70
RET-2	1977	SUMMER	T	0.133	0.101	0.751	0.156	0.285	0.037	0.45	31.87	5.24
RET-2	1977	FALL	T	.	.	.	0.065	.	.	0.49	.	7.51
LE-2	1977	SPRING	T	0.062	0.041	0.494	0.028	0.181	0.009	0.30	11.98	9.63
LE-2	1977	SUMMER	T	0.083	0.051	0.536	0.036	0.148	0.011	0.38	12.29	7.01
TF-3	1977	SPRING	T	0.149	0.031	0.727	0.129	0.260	0.006	0.46	.	8.21
TF-3	1977	SUMMER	T	0.122	0.020	.	0.216	.	0.052	0.55	.	6.33
TF-3	1977	SUMMER	B	.	.	.	0.117	.	0.052	0.40	.	6.40
TF-3	1977	FALL	T	0.208	0.028	.	.	.	0.021	.	.	7.69
RET-3	1977	SPRING	T	.	0.028	.	0.142	.	0.011	.	.	7.48
RET-3	1977	SUMMER	T	0.075	0.011	.	0.100	.	0.017	0.31	.	6.52
RET-3	1977	FALL	T	0.159	0.038	.	.	.	.	.	.	7.60
LE-3	1977	SPRING	T	.	0.022	.	0.069	.	0.008	.	.	8.31
LE-3	1977	SUMMER	T	0.053	0.008	.	0.082	.	0.012	0.40	.	5.53
LE-3	1977	FALL	T	0.138	0.034	.	.	.	.	.	.	6.62
TF-4	1977	SUMMER	T	0.120	0.020	.	0.100	.	0.012	0.38	.	5.58
TF-4	1977	FALL	T	0.073	0.018	0.347	.	0.039	0.015	0.28	.	6.15
RET-4	1977	SPRING	T	0.086	0.036	.	0.104	.	0.008	0.45	.	6.67
RET-4	1977	SUMMER	T	0.090	0.024	.	0.100	.	0.014	0.38	.	5.07
RET-4	1977	FALL	T	0.087	0.032	0.358	.	0.042	0.028	0.32	.	5.61
LE-4	1977	SPRING	T	.	0.023	.	0.126	.	0.008	.	.	7.81
LE-4	1977	SPRING	B	.	0.020	.	.	.	0.008	.	.	7.35
LE-4	1977	SUMMER	T	0.061	0.025	.	0.100	.	0.015	0.34	.	5.57
LE-4	1977	SUMMER	B	0.062	0.026	.	0.149	.	0.012	0.33	.	4.17
LE-4	1977	FALL	T	0.080	0.041	.	.	.	.	.	.	5.68
LE-4	1977	FALL	B	0.079	0.031	.	.	.	.	.	.	4.96

(continued)

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[1] Chlorophyll a, uncorrected

TABLE 38a. (Continued)

SEGMENT	YEAR	SEASON	LEVEL	TP	IPF	TN	NH3	NO3	NO2	TKN	CHL-AU	D.O.
TF-5	1977	SUMMER	T	0.168	0.034	.	0.219	.	0.059	0.66	.	5.75
TF-5	1977	FALL	T	.	.	.	.	.	.	0.60	.	6.87
LE-5	1977	SUMMER	T	0.092	0.033	.	0.107	.	0.031	0.44	.	6.32
LE-5	1977	SUMMER	B	.	.	.	.	.	.	.	.	5.94
LE-5	1977	FALL	T	.	.	.	.	.	.	.	.	7.27
LE-5	1977	FALL	B	.	.	.	.	.	.	.	.	7.09
ET-2	1977	SPRING	T	0.144	0.060	1.426	0.084	1.320	0.015	0.38	26.40	10.66
ET-2	1977	SUMMER	T	0.057	0.033	1.032	0.024	0.571	0.008	0.45	50.45	7.56
ET-3	1977	SUMMER	T	0.070	0.032	0.744	0.032	0.035	0.003	0.71	.	9.54
ET-4	1977	SPRING	T	0.170	0.038	1.369	0.212	0.720	0.021	0.63	61.50	9.84
ET-4	1977	SUMMER	T	0.082	0.057	0.617	0.020	0.041	0.006	0.57	85.74	7.46
ET-5	1977	SPRING	T	0.143	0.083	1.391	0.039	1.094	0.014	0.29	16.69	9.55
ET-5	1977	SUMMER	T	0.069	0.045	0.790	0.034	0.486	0.010	0.30	59.18	7.80
ET-6	1977	SPRING	T	0.105	0.046	1.699	0.095	1.435	0.021	0.25	26.54	9.51
ET-6	1977	SUMMER	T	0.057	0.041	0.433	0.033	0.065	0.009	0.36	45.75	7.21
ET-7	1977	SPRING	T	0.175	0.100	2.203	0.518	1.354	0.038	0.82	36.38	9.97
ET-7	1977	SUMMER	T	0.089	0.059	0.676	0.066	0.387	0.028	0.26	52.09	7.56
ET-10	1977	SPRING	T	0.100	0.066	1.440	0.122	0.912	0.012	0.52	9.00	7.81
ET-10	1977	SUMMER	T	0.079	0.052	0.444	0.068	0.150	0.006	0.29	26.44	6.98
EE-1	1977	SPRING	T	0.122	0.015	0.814	0.074	0.434	0.012	0.37	7.50	10.82
EE-1	1977	SUMMER	T	0.060	0.019	0.364	0.024	0.015	0.004	0.35	32.50	6.74
EE-3	1977	SPRING	T	0.059	0.019	0.751	0.079	0.140	0.013	0.60	19.13	9.34
EE-3	1977	SUMMER	T	0.069	0.034	0.640	0.049	0.027	0.006	0.61	24.72	6.45
WE-4	1977	SUMMER	T	.	.	.	.	.	.	.	.	5.81

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[1] Chlorophyll a, uncorrected

BLE 38B. SUMMARY STATISTICS FOR NUTRIENT MEANS (MG L-1 EXCEPT CHL-AU WHICH IS IN MICROGRAMS PER LITER)
(SEASONAL DATA)

SEGMENT	YEAR	SEASON	LEVEL	TP	IPF	TN	NH3	NO3	NO2	TKN	CHL-AU	D.O.
CB-1	1978	SUMMER	T	0.141	0.037	1.898	0.079	1.020	0.078	0.80	11.84	6.84
CB-1	1978	FALL	T	0.104	0.087	1.204	0.062	0.672	0.038	0.50	.	8.60
CB-2	1978	SPRING	T	0.212	.	.	0.194	1.199	0.018	.	44.70	13.54
CB-2	1978	SUMMER	T	0.150	0.039	1.354	0.063	0.691	0.025	0.73	18.56	7.56
CB-2	1978	FALL	T	0.063	0.054	0.984	0.064	0.389	0.024	0.57	25.73	8.56
CB-3	1978	SPRING	T	0.230	0.043	2.231	0.215	1.118	0.021	1.09	8.32	12.32
CB-3	1978	SPRING	B	.	.	.	.	.	.	.	.	10.50
CB-3	1978	SUMMER	T	0.178	0.056	1.077	0.090	0.381	0.017	0.81	11.32	6.48
CB-3	1978	FALL	T	0.085	0.069	0.671	0.057	0.097	0.033	0.54	19.07	8.29
CB-4	1978	SPRING	T	0.152	0.030	1.465	0.137	0.688	0.021	0.83	8.08	12.14
CB-4	1978	SPRING	B	.	.	.	.	.	.	.	.	9.94
CB-4	1978	SUMMER	T	0.163	0.034	0.935	0.074	0.210	0.010	0.89	11.14	6.80
CB-4	1978	SUMMER	B	0.168	0.047	1.072	0.267	0.150	0.011	1.04	5.75	1.02
CB-4	1978	FALL	T	0.061	0.052	0.558	0.066	0.028	0.029	0.50	10.09	7.57
CB-4	1978	FALL	B	0.071	0.061	0.639	0.159	0.033	0.054	0.55	7.30	1.86
CB-5	1978	SPRING	T	0.150	.	1.370	0.108	0.614	0.027	0.73	11.84	11.34
CB-5	1978	SUMMER	T	0.137	0.033	0.992	0.077	0.156	0.008	0.87	10.03	7.17
CB-5	1978	SUMMER	B	.	.	.	.	.	.	.	.	2.92
CB-5	1978	FALL	T	0.094	0.047	0.629	0.045	0.028	0.028	0.57	8.74	7.73
CB-5	1978	FALL	B	0.113	.	0.648	0.056	0.049	0.017	0.59	6.71	5.11
WT-2	1978	SUMMER	T	.	.	.	.	.	.	.	.	10.25
WT-5	1978	SPRING	T	.	.	.	.	.	.	.	.	10.07
WT-5	1978	SUMMER	T	0.188	0.047	1.652	0.440	0.388	0.090	1.25	18.06	6.96
WT-5	1978	FALL	T	0.079	0.058	1.361	0.589	0.352	0.041	0.97	22.39	6.17
TF-1	1978	SPRING	T	0.313	.	2.072	0.431	1.135	0.055	0.89	.	8.48
TF-1	1978	SUMMER	T	0.388	.	2.358	0.162	1.073	0.069	1.19	43.56	6.72
TF-1	1978	SUMMER	B	0.354	.	2.525	0.082	1.042	0.049	1.44	.	7.44
TF-1	1978	FALL	T	0.678	.	2.962	0.395	1.806	0.088	1.07	32.62	7.52
RET-1	1978	SPRING	T	0.148	.	1.389	0.129	0.513	0.018	0.85	.	9.01
RET-1	1978	SUMMER	T	0.151	.	0.974	0.087	0.072	0.005	0.90	24.49	4.88
RET-1	1978	FALL	T	0.152	.	0.760	0.088	0.092	0.055	0.61	11.58	6.70
LE-1	1978	SPRING	T	0.173	.	1.290	0.165	0.423	0.013	0.86	.	9.79
LE-1	1978	SUMMER	T	0.109	.	0.939	0.065	0.056	0.006	0.93	.	5.26
LE-1	1978	SUMMER	B	.	.	.	.	.	.	.	.	1.43
LE-1	1978	FALL	T	0.089	.	0.581	0.042	0.038	0.052	0.49	9.66	7.33
TF-2	1978	SPRING	T	0.224	0.067	.	0.189	0.914	0.022	.	27.62	10.85
TF-2	1978	SPRING	B	.	.	.	.	.	.	.	.	9.89
TF-2	1978	SUMMER	T	0.141	0.087	1.473	0.308	0.599	0.061	0.83	39.92	7.28
TF-2	1978	SUMMER	B	.	.	.	.	.	.	.	.	5.20

(continued)

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[1] Chlorophyll *a*, uncorrected

TABLE 38b. (Continued)

TF-2	1978	FALL	T	0.117	0.070	1.782	0.162	0.776	0.128	0.85	52.05	8.65
TF-2	1978	FALL	B	.	.	.	.	.	.	.	.	6.32
RET-2	1978	SPRING	T	0.156	0.076	.	0.102	0.897	0.023	.	17.28	8.69
RET-2	1978	SPRING	B	.	.	.	.	.	.	.	.	7.37
RET-2	1978	SUMMER	T	0.184	0.149	0.875	0.045	0.439	0.025	0.42	28.67	6.06
RET-2	1978	FALL	T	0.117	0.134	0.803	0.057	0.252	0.027	0.56	21.58	6.69
TF-3	1978	SUMMER	T	0.193	0.029	1.167	0.115	0.566	0.015	0.52	.	6.95
TF-3	1978	SUMMER	B	.	.	.	.	.	.	0.40	.	7.74
TF-3	1978	FALL	T	0.097	0.047	0.686	0.111	.	.	0.43	.	9.25
RET-3	1978	SUMMER	T	0.115	0.017	0.582	0.082	0.065	0.005	0.51	.	6.92
RET-3	1978	FALL	T	0.084	0.035	0.529	0.051	.	.	0.41	.	8.40
LE-3	1978	SUMMER	T	0.045	0.013	.	0.151	.	0.003	0.71	.	5.99
LE-3	1978	SUMMER	B	0.082	0.026	.	0.183	.	0.003	0.68	.	2.82
LE-3	1978	FALL	T	0.057	0.020	0.452	0.073	.	.	0.36	.	7.87
TF-4	1978	SUMMER	T	0.164	0.035	.	.	0.092	0.009	0.52	.	5.28
TF-4	1978	FALL	T	0.132	0.024	0.532	0.057	0.048	0.007	0.49	.	6.71
RET-4	1978	SUMMER	T	0.128	0.029	.	.	0.059	0.016	0.51	.	5.28
RET-4	1978	FALL	T	0.112	0.031	.	.	0.124	0.018	.	.	5.77
LE-4	1978	SUMMER	T	0.092	0.024	.	.	0.057	0.042	0.50	.	5.71
LE-4	1978	SUMMER	B	0.092	0.023	.	.	0.057	0.049	0.46	.	3.92
LE-4	1978	FALL	T	0.104	0.041	.	.	0.137	0.039	.	.	5.99
LE-4	1978	FALL	B	0.109	0.044	.	.	0.086	0.035	.	.	5.36
TF-5	1978	SUMMER	T	0.190	0.104	1.018	0.104	0.411	0.025	0.50	.	6.86
TF-5	1978	SUMMER	B	.	.	.	.	.	.	.	.	6.18
TF-5	1978	FALL	T	0.231	0.152	1.602	0.242	.	.	0.66	.	8.27
TF-5	1978	FALL	B	.	.	.	0.218	.	.	0.65	.	7.74
RET-5	1978	SUMMER	T	.	.	.	.	.	.	.	.	6.42
LE-5	1978	SUMMER	T	0.116	0.042	.	0.075	0.309	0.025	0.32	.	6.67
LE-5	1978	FALL	T	0.089	0.044	0.781	0.184	.	.	0.38	.	7.95
ET-5	1978	SUMMER	T	.	.	.	.	.	.	.	.	7.29
ET-10	1978	SPRING	T	.	.	.	.	.	.	.	.	8.05

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[1] Chlorophyll a, uncorrected

(SEASONAL DATA)

SEGMENT	YEAR	SEASON	LEVEL	TP	IPF	TN	NH3	NO3	NO2	TKN	CHL-AU	D.O.
CB-1	1979	SUMMER	T	0.096	.	.	0.075	.	0.052	0.45	22.38	7.74
CB-1	1979	FALL	T	0.106	0.048	.	0.049	1.219	0.020	0.42	12.00	9.38
CB-2	1979	SPRING	T	0.123	0.028	1.405	0.081	0.825	0.018	0.60	11.68	9.88
CB-2	1979	SUMMER	T	0.161	0.044	1.335	0.042	0.611	0.023	0.40	21.73	7.59
CB-2	1979	FALL	T	0.160	0.046	.	0.051	1.180	0.023	0.47	13.37	9.40
CB-3	1979	SPRING	T	0.069	0.019	1.404	0.100	0.456	0.017	0.62	17.12	8.96
CB-3	1979	SUMMER	T	0.106	0.049	0.913	0.105	0.165	0.015	0.44	25.19	6.13
CB-3	1979	FALL	T	0.102	0.041	1.253	0.075	0.558	0.072	0.50	17.49	8.49
CB-3	1979	WINTER	T	0.023	.	.	0.139	0.174	0.012	.	13.33	.
CB-4	1979	SPRING	T	0.033	0.016	1.084	0.073	0.378	0.016	0.50	29.02	9.16
CB-4	1979	SPRING	B	0.032	0.015	1.035	0.133	0.384	0.018	0.61	35.39	5.54
CB-4	1979	SUMMER	T	0.080	0.082	.	0.098	0.102	0.018	0.44	18.24	5.74
CB-4	1979	FALL	T	0.073	0.047	.	0.045	.	0.167	0.46	13.03	7.02
CB-5	1979	SPRING	T	0.013	0.010	1.058	0.026	0.187	0.017	0.56	20.17	10.45
CB-5	1979	SPRING	B	0.004	.	.	0.071	0.113	0.016	.	22.23	.
CB-5	1979	SUMMER	T	0.020	.	.	0.079	0.067	0.007	0.53	4.48	6.33
CB-5	1979	FALL	T	0.030	0.030	0.796	0.027	0.010	0.158	0.63	11.73	8.48
CB-5	1979	WINTER	T	0.011	.	.	0.049	0.041	0.009	.	6.38	.
CB-7	1979	SPRING	T	.	.	.	0.026	0.007	.	.	5.56	.
WT-5	1979	SPRING	T	0.062	0.019	2.037	0.416	0.826	0.032	1.18	22.20	9.49
WT-5	1979	SUMMER	T	0.090	0.034	2.252	0.204	0.541	0.024	0.77	30.12	7.01
WT-5	1979	FALL	T	0.075	0.028	1.807	0.304	0.780	0.056	0.97	28.88	7.03
WT-5	1979	WINTER	T	.	.	.	.	.	.	.	.	9.53
TF-2	1979	SPRING	T	0.091	0.051	1.725	0.270	0.886	0.022	0.68	11.53	9.87
TF-2	1979	SPRING	B	.	.	.	.	.	.	.	.	9.14
TF-2	1979	SUMMER	T	0.121	0.057	1.692	0.310	0.676	0.087	0.70	28.43	7.32
TF-2	1979	SUMMER	B	.	.	.	.	.	.	.	.	6.59
TF-2	1979	FALL	T	0.112	0.049	1.633	0.332	0.905	0.028	0.70	18.54	8.94
TF-2	1979	FALL	B	.	.	.	.	.	.	.	.	10.05
RET-2	1979	SPRING	T	0.116	0.048	1.808	0.221	1.042	0.016	0.72	18.28	9.42
RET-2	1979	SPRING	B	.	.	.	.	.	.	.	.	8.27
RET-2	1979	SUMMER	T	0.124	0.064	1.151	0.070	0.434	0.052	0.51	28.15	6.91
RET-2	1979	FALL	T	0.084	0.051	1.723	0.128	1.036	0.018	0.63	21.25	8.20
RET-2	1979	FALL	B	.	.	.	.	.	.	.	.	6.99
LE-2	1979	SUMMER	T	0.049	.	.	0.170	.	.	0.38	.	5.91
TF-3	1979	SUMMER	T	.	.	.	.	.	.	.	.	7.37

(continued)

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[1] Chlorophyll a, uncorrected

TABLE 38c. (Continued)

SEGMENT	YEAR	SEASON	LEVEL	TP	IPF	TN	NH3	NO3	NO2	TKN	CHL-AU	D.O.
RET-3	1979	SUMMER	T	.	.	.	.	.	.	.	.	6.79
RET-3	1979	FALL	T	.	.	.	.	.	.	.	.	8.12
LE-3	1979	SUMMER	T	.	.	.	0.007	0.016	0.000	.	.	6.45
LE-3	1979	SUMMER	B	.	.	.	.	.	.	.	.	3.39
LE-3	1979	FALL	T	.	.	.	0.063	0.074	0.032	.	.	7.58
LE-3	1979	FALL	B	.	.	.	.	.	.	.	.	7.23
TF-4	1979	SUMMER	T	.	.	.	.	.	.	.	.	5.22
RET-4	1979	SUMMER	T	.	.	.	.	.	.	.	.	5.23
RET-4	1979	FALL	T	.	.	.	.	.	.	.	.	7.51
LE-4	1979	SUMMER	T	.	.	.	.	.	.	.	.	5.34
LE-4	1979	SUMMER	B	.	.	.	.	.	.	.	.	4.72
LE-4	1979	FALL	T	.	.	.	.	.	.	.	.	7.20
LE-4	1979	FALL	B	.	.	.	.	.	.	.	.	5.40
TF-5	1979	SPRING	T	0.180	0.090	.	0.119	0.380	.	0.47	.	9.20
TF-5	1979	SPRING	B	0.167	0.080	.	0.240	0.351	.	0.87	.	7.99
TF-5	1979	SUMMER	T	0.189	0.051	.	0.205	0.467	.	0.56	.	6.57
TF-5	1979	SUMMER	B	0.245	0.023	.	0.194	0.758	.	0.73	.	5.99
TF-5	1979	FALL	T	0.143	0.054	0.799	0.179	.	.	0.42	.	8.90
TF-5	1979	WINTER	T	0.141	0.102	.	0.326	.	.	0.58	.	11.35
RET-5	1979	SPRING	T	.	.	.	.	.	.	.	.	8.22
RET-5	1979	SUMMER	T	.	.	.	.	.	.	.	.	6.55
RET-5	1979	FALL	T	.	.	.	.	.	.	.	.	7.96
LE-5	1979	SPRING	T	0.139	0.046	.	0.079	0.399	.	0.44	.	8.70
LE-5	1979	SUMMER	T	0.131	0.032	.	0.088	0.462	.	0.49	.	6.66
LE-5	1979	SUMMER	B	.	.	.	.	.	.	.	.	6.22
LE-5	1979	FALL	T	0.114	0.043	0.773	0.098	.	.	0.36	.	8.17
LE-5	1979	WINTER	T	0.062	0.040	.	0.245	.	.	0.37	.	10.36
ET-3	1979	SUMMER	T	0.097	.	.	.	.	.	0.38	.	7.60
ET-5	1979	SUMMER	T	0.076	0.062	1.895	0.063	1.275	0.013	0.61	17.64	7.70
WE-4	1979	SUMMER	T	.	.	.	.	.	.	.	.	6.22

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[1] Chlorophyll a, uncorrected

TABLE 38d. SUMMARY STATISTICS FOR NUTRIENT MEANS (MG L^{-1} EXCEPT CHL-AU[1] WHICH IS IN MICROGRAMS PER LITER) (SEASONAL DATA)

SEGMENT	YEAR	SEASON	LEVEL	TP	IPF	TN	NH3	NO3	NO2	TKN	CHL-AU	D.O.
CB-1	1980	SPRING	T	0.050	0.020	1.462	0.047	1.082	0.012	0.37	20.80	10.24
CB-1	1980	SUMMER	T	0.067	0.012	1.468	0.090	0.815	0.034	0.62	38.70	7.60
CB-2	1980	SPRING	T	0.052	0.021	1.519	0.039	1.053	0.013	0.46	11.92	10.83
CB-2	1980	SUMMER	T	0.085	0.018	1.270	0.054	0.570	0.013	0.70	47.46	7.25
CB-3	1980	SPRING	T	0.053	0.042	1.593	0.098	0.808	0.015	0.80	19.37	9.36
CB-3	1980	SUMMER	T	0.068	0.055	1.469	0.256	0.154	0.008	1.12	26.43	6.09
CB-3	1980	SUMMER	B	.	.	.	.	.	.	.	.	4.12
CB-3	1980	FALL	T	.	0.083	2.318	0.389	0.386	0.058	.	.	8.64
CB-3	1980	WINTER	T	.	.	.	.	.	.	.	.	12.49
CB-4	1980	SPRING	T	0.052	0.025	1.307	0.044	0.516	0.007	0.79	34.29	10.03
CB-4	1980	SPRING	B	0.054	0.033	1.192	0.070	0.363	0.006	0.83	17.67	7.08
CB-4	1980	SUMMER	T	0.071	0.029	0.890	0.118	0.056	0.003	0.83	17.71	6.45
CB-4	1980	SUMMER	B	0.066	0.036	0.807	0.203	0.042	0.003	0.76	8.92	2.52
CB-5	1980	SPRING	T	0.040	0.029	1.152	0.024	0.387	0.006	0.76	15.78	.
CB-5	1980	SUMMER	T	0.044	0.023	0.788	0.100	0.033	0.003	0.75	9.81	6.50
CB-5	1980	SUMMER	B	.	.	.	.	.	.	.	.	2.89
WT-4	1980	SPRING	T	.	.	.	1.792	0.922	0.268	.	.	9.12
WT-4	1980	SUMMER	T	.	.	5.319	1.873	0.538	0.352	2.85	160.82	4.86
WT-4	1980	FALL	T	.	.	.	2.084	1.692	0.333	.	.	6.09
WT-4	1980	WINTER	T	.	.	.	.	.	.	.	.	11.87
WT-5	1980	SPRING	T	0.077	0.025	2.108	0.363	1.088	0.023	1.10	17.45	9.14
WT-5	1980	SUMMER	T	0.139	0.034	2.059	0.225	0.438	0.017	1.61	48.87	6.08
WT-5	1980	FALL	T	.	.	.	.	.	.	.	.	6.42
WT-5	1980	WINTER	T	.	.	.	.	.	.	.	.	10.83
TF-1	1980	SUMMER	T	0.342	0.164	.	0.171	1.031	0.079	.	28.44	6.31
TF-1	1980	FALL	T	.	.	.	.	.	.	.	32.32	8.92
LE-1	1980	SUMMER	T	0.053	0.024	.	0.070	0.020	0.025	.	9.87	5.66
LE-1	1980	FALL	T	.	.	.	.	.	.	.	15.27	8.02
TF-2	1980	SPRING	T	0.092	0.039	1.694	0.169	1.047	0.018	0.63	14.19	10.24
TF-2	1980	SPRING	B	.	.	.	.	.	.	.	.	10.17
TF-2	1980	SUMMER	T	0.114	0.029	2.004	0.415	0.638	0.091	0.99	49.89	7.06
TF-2	1980	SUMMER	B	.	.	.	.	.	.	.	.	5.70
TF-2	1980	FALL	T	0.091	0.020	.	0.493	.	.	1.06	.	8.59
RET-2	1980	SPRING	T	0.114	0.032	1.892	0.203	1.045	0.022	0.83	31.27	9.83
RET-2	1980	SUMMER	T	0.126	0.046	1.307	0.070	0.398	0.028	0.75	40.59	6.45
RET-2	1980	SUMMER	B	.	.	.	.	.	.	.	.	4.72
RET-2	1980	FALL	T	0.093	.	.	0.049	.	.	0.72	.	.

(continued)

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[1] Chlorophyll a, uncorrected

TABLE 38d. (Continued)

SEGMENT	YEAR	SEASON	LEVEL	TP	IPF	TN	NH3	NO3	NO2	TKN	CHL-AU	D.O.
LE-2	1980	SUMMER	T	0.064	.	.	0.039	.	.	0.53	.	.
LE-3	1980	SPRING	T	.	.	.	0.100	0.034	0.000	.	.	12.27
LE-3	1980	SUMMER	T	.	.	.	0.029	0.003	0.002	.	.	7.06
LE-3	1980	SUMMER	B	.	.	.	.	.	.	.	.	4.33
LE-3	1980	FALL	T	.	.	.	0.000	0.029	0.018	.	.	9.95
TF-4	1980	SUMMER	T	.	.	.	.	.	.	.	.	6.11
TF-5	1980	SUMMER	T	.	.	.	.	.	.	.	.	7.13
RET-5	1980	SUMMER	T	.	.	.	.	.	.	.	.	7.11
LE-5	1980	SUMMER	T	.	.	.	.	.	.	.	.	5.52
LE-5	1980	SUMMER	B	.	.	.	.	.	.	.	.	5.89
ET-4	1980	SUMMER	T	0.147	0.022	0.663	0.063	0.233	0.012	0.42	.	.
ET-4	1980	FALL	T	0.303	.	1.002	0.165	0.426	0.110	0.65	.	10.10
ET-5	1980	SUMMER	T	0.101	0.045	1.752	0.050	1.209	0.015	0.82	.	7.38
WE-4	1980	SUMMER	T	.	.	.	.	.	.	.	.	6.67
WE-4	1980	SUMMER	B	.	.	.	.	.	.	.	.	3.45

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[1] Chlorophyll _a_, uncorrected

TABLE 39. SUMMARY STATISTICS FOR THE CHESAPEAKE BAY PROGRAM NUTRIENTS DATA BASE FOR SELECTED PARAMETERS WITH MONTHLY STATISTICS, INCLUDING MEANS, NUMBER OF OBSERVATIONS, STANDARD DEVIATION MINIMUM AND MAXIMUM FOR DEPTH AVERAGED -A-

OBS	SEGMENT	IPF	N_IPF	S_IPF	L_IPF	U_IPF	TP	N_TP	S_TP	L_TP	U_TP	CHL_AU	N_CHL	S_CHL	L_CHL	U_CHL	YEAR	MONTH
1	CB-1	0.020	3	0.000	0.020	0.020	0.047	3	0.006	0.04	0.05	23.40	3	31.73	3.60	60.00	1980	4
2	CB-1	0.020	3	0.000	0.020	0.020	0.053	3	0.040	0.03	0.10	18.20	3	6.60	11.70	24.90	1980	5
3	CB-1	0.013	3	0.006	0.010	0.020	0.057	3	0.015	0.04	0.07	27.43	3	8.23	22.00	36.90	1980	6
4	CB-1	0.010	5	0.000	0.010	0.010	0.076	5	0.021	0.04	0.09	49.96	5	49.07	7.40	105.00	1980	7
5	CB-1	0.010	1	.	0.010	0.010	0.030	1	.	0.03	0.03	24.45	1	.	24.45	24.45	1980	8
6	CB-1	0.010	1	.	0.010	0.010	0.040	1	.	0.04	0.04	56.10	1	.	56.10	56.10	1980	10
7	CB-1	0.040	1	.	0.040	0.040	0.110	1	.	0.11	0.11	46.35	1	.	46.35	46.35	1980	12
8	CB-2	0.021	7	0.004	0.020	0.030	0.064	7	0.008	0.05	0.07	4.89	7	0.88	3.60	6.00	1980	4
9	CB-2	0.020	7	0.000	0.020	0.020	0.040	7	0.006	0.03	0.05	17.66	7	5.27	9.90	23.10	1980	5
10	CB-2	0.019	7	0.007	0.010	0.030	0.079	7	0.015	0.05	0.10	43.65	6	31.20	27.90	107.10	1980	6
11	CB-2	0.017	14	0.005	0.010	0.020	0.089	14	0.018	0.07	0.14	46.64	14	37.30	8.40	114.00	1980	7
12	CB-3	0.062	16	0.107	0.020	0.440	0.065	13	0.013	0.04	0.08	6.51	13	2.47	3.00	10.80	1980	4
13	CB-3	0.019	16	0.012	0.000	0.050	0.040	13	0.010	0.03	0.06	32.10	13	24.44	9.90	100.20	1980	5
14	CB-3	0.023	13	0.006	0.020	0.040	0.054	13	0.014	0.03	0.08	20.73	13	10.56	8.25	49.60	1980	6
15	CB-3	0.023	113	0.036	0.004	0.350	0.085	45	0.050	0.02	0.24	27.40	95	32.85	1.62	186.00	1980	7
16	CB-3	0.119	7	0.138	0.010	0.420	0.050	1	.	0.05	0.05	56.11	2	22.71	40.05	72.17	1980	8
17	CB-3	0.113	3	0.049	0.080	0.170	.	0	.	.	.	.	0	.	.	.	1980	9
18	CB-3	0.052	16	0.050	0.020	0.180	0.069	14	0.012	0.05	0.09	42.63	13	26.43	13.20	73.66	1980	10
19	CB-3	.	0	.	.	.	0.120	2	0.113	0.04	0.20	.	0	.	.	.	1980	11
20	CB-3	0.066	7	0.061	0.020	0.170	0.151	7	0.172	0.04	0.45	65.96	7	34.40	21.55	110.19	1980	12
21	CB-4	0.025	24	0.010	0.010	0.060	0.049	24	0.009	0.04	0.07	13.61	24	5.80	7.65	28.65	1980	4
22	CB-4	0.028	24	0.010	0.020	0.050	0.055	24	0.021	0.03	0.10	45.91	22	27.43	10.20	124.50	1980	5
23	CB-4	0.037	24	0.009	0.030	0.070	0.051	24	0.010	0.04	0.08	16.04	24	6.51	7.20	28.60	1980	6
24	CB-4	0.025	142	0.016	0.005	0.099	0.087	49	0.045	0.05	0.27	13.57	141	18.11	0.42	122.00	1980	7
25	CB-4	0.015	24	0.005	0.010	0.020	0.049	24	0.014	0.03	0.09	40.70	24	22.22	8.63	90.29	1980	10
26	CB-5	0.030	4	0.008	0.020	0.040	0.043	4	0.005	0.04	0.05	13.39	4	2.39	9.90	15.30	1980	4
27	CB-5	0.030	4	0.008	0.020	0.040	0.038	4	0.005	0.03	0.04	27.41	4	20.90	4.35	54.15	1980	5
28	CB-5	0.032	6	0.013	0.010	0.040	0.050	6	0.013	0.03	0.06	15.38	6	6.26	6.11	20.70	1980	6
29	CB-5	0.017	182	0.009	0.003	0.054	0.042	35	0.014	0.03	0.08	3.74	184	4.05	0.05	24.81	1980	7
30	CB-5	0.015	2	0.007	0.010	0.020	0.035	2	0.007	0.03	0.04	6.98	2	4.00	4.15	9.81	1980	8
31	CB-5	0.030	2	0.000	0.030	0.030	0.030	2	0.000	0.03	0.03	5.70	2	2.81	3.71	7.69	1980	9
32	CB-5	0.018	4	0.005	0.010	0.020	0.040	4	0.000	0.04	0.04	20.99	6	13.31	8.23	34.50	1980	10
33	CB-5	.	0	.	.	.	.	0	.	.	.	11.35	2	4.48	8.18	14.52	1980	11
34	CB-5	.	0	.	.	.	.	0	.	.	.	13.17	2	0.27	12.98	13.36	1980	12
35	CB-6	0.026	125	0.014	0.005	0.081	.	0	.	.	.	3.86	125	3.05	0.30	18.43	1980	7
36	CB-7	0.026	125	0.016	0.002	0.077	.	0	.	.	.	3.38	126	2.75	0.43	15.86	1980	7
37	WT-1	0.080	1	.	0.080	0.080	0.220	1	.	0.22	0.22	.	0	.	.	.	1980	6
38	WT-2	0.010	1	.	0.010	0.010	0.040	1	.	0.04	0.04	18.00	1	.	18.00	18.00	1980	7
39	WT-3	0.010	1	.	0.010	0.010	0.080	1	.	0.08	0.08	10.60	1	.	10.60	10.60	1980	7
40	WT-4	0.305	2	0.177	0.180	0.430	0.450	1	.	0.45	0.45	.	0	.	.	.	1980	4
41	WT-4	0.085	2	0.106	0.010	0.160	.	0	.	.	.	.	0	.	.	.	1980	5
42	WT-4	0.375	4	0.061	0.300	0.430	0.210	1	.	0.21	0.21	152.36	9	65.63	80.19	264.63	1980	7
43	WT-4	0.305	2	0.233	0.140	0.470	.	0	.	.	.	169.29	6	69.29	74.84	240.57	1980	8
44	WT-4	0.235	2	0.163	0.120	0.350	.	0	.	.	.	.	0	.	.	.	1980	9
45	WT-4	0.335	2	0.035	0.310	0.360	.	0	.	.	.	85.00	5	31.88	53.46	128.31	1980	10
46	WT-4	.	0	.	.	.	.	0	.	.	.	49.45	6	13.71	29.40	66.83	1980	12
47	WT-5	0.030	5	0.007	0.020	0.040	0.086	5	0.009	0.08	0.10	8.70	4	1.87	6.00	10.20	1980	4
48	WT-5	0.022	5	0.004	0.020	0.030	0.066	5	0.011	0.05	0.08	23.40	4	6.40	15.00	29.10	1980	5
49	WT-5	0.026	5	0.009	0.020	0.040	0.140	5	0.057	0.08	0.20	50.91	5	53.59	7.35	143.40	1980	6
50	WT-5	0.038	9	0.007	0.030	0.050	0.145	8	0.032	0.10	0.18	37.17	9	37.51	6.90	131.10	1980	7

TABLE 40. SUMMARY OF STATISTICALLY SIGNIFICANT ANNUAL NUTRIENT TRENDS DETERMINED BY PEARSON'S CORRELATION

Segment	TP	IPF	TN	NO_3	NO_2	NH_3	TKN	CHL-AU
CB-1	+	+	0	+	0	0	0	0
CB-2	+	+	0	+	0	0	0	+
CB-3	0	0	0	0	+	0	0	+
CB-4	0	0	0	0	0	0	0	+
CB-5	+	0	0	0	0	0	0	0
CB-6								
CB-7								+
CB-8								
WT-1								
WT-2								
WT-3								
WT-4				0				
WT-5	0	0	0	0	0	0	0	0
WT-6	0			0	0	0		+
WT-7								
WT-8	0	0	0	0	0	0	0	0
TF-1	0	0	+	+	0	0	+	0
RET-1		+		0	0	0	0	
LE-1		0		0	0			
TF-2	–	0	0	+	0	–	–	0
RET-2	0	0	0	+	0	0	0	0
LE-2	0	+	–	0	+	0	–	0
TF-3								
RET-3		+		0	0	0	0	
LE-3	+	0		0	0	0	0	
TF-4				0	0	0	0	
RET-4	0	0	0	0	0	0	0	0
LE-4		0						
TF-5	0	–	–	0	0	0	0	
RET-5						0		
LE-5	0	–	0	0	0	0	0	

(continued)

TABLE 40. (continued)

Segment	TP	IPF	TN	NO_3	NO_2	NH_3	TKN	CHL-AU
ET-1	0	0	-			0	-	
ET-2	0	+	0	+	0	0	-	-
ET-3	0	0	0			0	0	
ET-4	0	+	+	+	0	0	0	+
ET-5	0	+	0	0	0	0	0	+
ET-6	0	0	0	+	0	0	-	0
ET-7	0	0	-	+	0	0	-	0
ET-8								
ET-9								
ET-10	0	0	0	0	0	0	0	+
EE-1	0	0	0	0	0	0		0
EE-2		0						
EE-3		+						
WE-4					0	0		

+ = increasing, 0 = no trend,
- = decreasing, blank = limited data,

TABLE 41a. SUMMARY OF STATISTICALLY SIGNIFICANT SEASONAL NUTRIENT TRENDS DETERMINED BY PEARSON'S CORRELATION - SPRING

Segment	TP	IPF	TN	NO_3	NO_2	NH_3	TKN	CHL-AU
CB-1	0	0	0			–	0	
CB-2	0	0	0	+	0	0	0	0
CB-3	0	0	0	0	0	0	0	+
CB-4	0	0	0	+	0	0	0	+
CB-5	0	0	0	0	0	0	0	+
CB-6								
CB-7		0						
CB-8								+
WT-1								
WT-2								
WT-3								
WT-4				0				
WT-5	0							
WT-6								
WT-7								
WT-8								
TF-1	0	0						
RET-1								
LE-1								
TF-2	0	0	–	+	0	–	0	0
RET-2	0	0	0	+	0	–	0	+
LE-2	0	0	–			0	0	0
TF-3								
RET-3								
LE-3								
TF-4								
RET-4					0	0	0	
LE-4								
TF-5								
RET-5								
LE-5		0			0	0		

(continued)

TABLE 41a. (continued)

Segment	TP	IPF	TN	NO_3	NO_2	NH_3	TKN	CHL-AU
ET-1								
ET-2	0	0	-			0		
ET-3	0	0	0			0	0	
ET-4	0	0		+	0	0		0
ET-5								
ET-6								
ET-7								
ET-8								
ET-9								
ET-10								
EE-1	0	0		0	0	0		0
EE-2								
EE-3		0						
WE-4								

+ = increasing, 0 = no trend,
- = decreasing, blank = limited data,

TABLE 41b. SUMMARY OF STATISTICALLY SIGNIFICANT SEASONAL NUTRIENT TRENDS DETERMINED BY PEARSON'S CORRELATION - SUMMER

Segment	TP	IPF	TN	NO_3	NO_2	NH_3	TKN	CHL-AU
CB-1	0	0	0		0	+	0	+
CB-2	+	0	0	+	+	0	0	0
CB-3	0	0	0	0	0	0	0	0
CB-4	0	0	0	0	0	0	0	0
CB-5	0	0		0	0	0	0	0
CB-6								
CB-7								
CB-8								
WT-1								
WT-2								
WT-3								
WT-4				0				
WT-5	0		0	0	0	–	0	0
WT-6								
WT-7	0	0		0	0			+
WT-8	0			0	0			0
TF-1	–	0	+	+	0	0	0	0
RET-1								
LE-1		0		+	0			
TF-2	0	0	–	0	0	0	–	0
RET-2	0	0	0	0	0	0	0	0
LE-2	0	0	0	0	0	0	0	0
TF-3								
RET-3					0	0	0	
LE-3				0	0	0	0	
TF-4					+	0	0	
RET-4				0	0	0	0	
LE-4								
TF-5	0	0	–	0	–	0	0	
RET-5								
LE-5	0	–		0	–	0	0	

(continued)

TABLE 41b. (continued)

Segment	TP	IPF	TN	NO_3	NO_2	NH_3	TKN	CHL-AU
ET-1	0	0	0			0	0	
ET-2	0	0	0	0	0	0	-	0
ET-3	0	0	0			0	0	
ET-4	0	0		0	0			
ET-5	0	+	0	0	0	0	0	0
ET-6								
ET-7	0	0	0			0	0	
ET-8								
ET-9								
ET-10								
EE-1								+
EE-2								
EE-3								
WE-4								

+ = increasing, 0 = no trend,
- = decreasing, blank = limited data,

TABLE 41c. SUMMARY OF STATISTICALLY SIGNIFICANT SEASONAL NUTRIENT TRENDS DETERMINED BY PEARSON'S CORRELATION - FALL

Segment	TP	IPF	TN	NO_3	NO_2	NH_3	TKN	CHL-AU
CB-1	0	0		+	0	0		
CB-2	0	+		0	+	0	0	0
CB-3	0	+	0	0	+	0	0	0
CB-4	0	0	0	0	0	0	0	0
CB-5		+		0	0	0		+
CB-6								
CB-7								
CB-8								
WT-1								
WT-2								
WT-3								
WT-4				0				
WT-5	0		0			0	0	
WT-6								
WT-7								
WT-8	0			0	0			
TF-1	0			+	-			
RET-1								
LE-1								
TF-2	0	0	0	0	0	0	0	0
RET-2	0	0	0	0	0	0	0	0
LE-2								
TF-3								
RET-3								
LE-3				0	0	0		
TF-4					+	0	0	
RET-4								
LE-4								
TF-5	0	0		0	0	0	0	
RET-5								
LE-5		-				0	0	

(continued)

TABLE 41c. (continued)

Segment	TP	IPF	TN	NO_3	NO_2	NH_3	TKN	CHL-AU
ET-1								
ET-2								
ET-3								
ET-4	0	0		+	0	0		0
ET-5								
ET-6								
ET-7								
ET-8								
ET-9								
ET-10								
EE-1		0						
EE-2								
EE-3								
WE-4								

+ = increasing, 0 = no trend,
- = decreasing, blank = limited data,

TABLE 41d. SUMMARY OF STATISTICALLY SIGNIFICANT SEASONAL NUTRIENT TRENDS DETERMINED BY PEARSON'S CORRELATION - WINTER

Segment	TP	IPF	TN	NO_3	NO_2	NH_3	TKN	CHL-AU
CB-1								
CB-2								
CB-3	0	0		0	0			0
CB-4	0	-		0	+	0		
CB-5		0						
CB-6								
CB-7								
CB-8								
WT-1								
WT-2								
WT-3								
WT-4								
WT-5								
WT-6								
WT-7								
WT-8								
TF-1								
RET-1								
LE-1								
TF-2	0	0	0			0	0	
RET-2	0	0				0	0	
LE-2								
TF-3								
RET-3								
LE-3								
TF-4								
RET-4								
LE-4								
TF-5								
RET-5								
LE-5								

(continued)

TABLE 41d. (continued)

Segment	TP	IPF	TN	NO_3	NO_2	NH_3	TKN	CHL-AU
ET-1								
ET-2								
ET-3								
ET-4								
ET-5								
ET-6								
ET-7								
ET-8								
ET-9								
ET-10								
EE-1								
EE-2								
EE-3								
WE-4								

+ = increasing, 0 = no trend,
- = decreasing, blank = limited data,

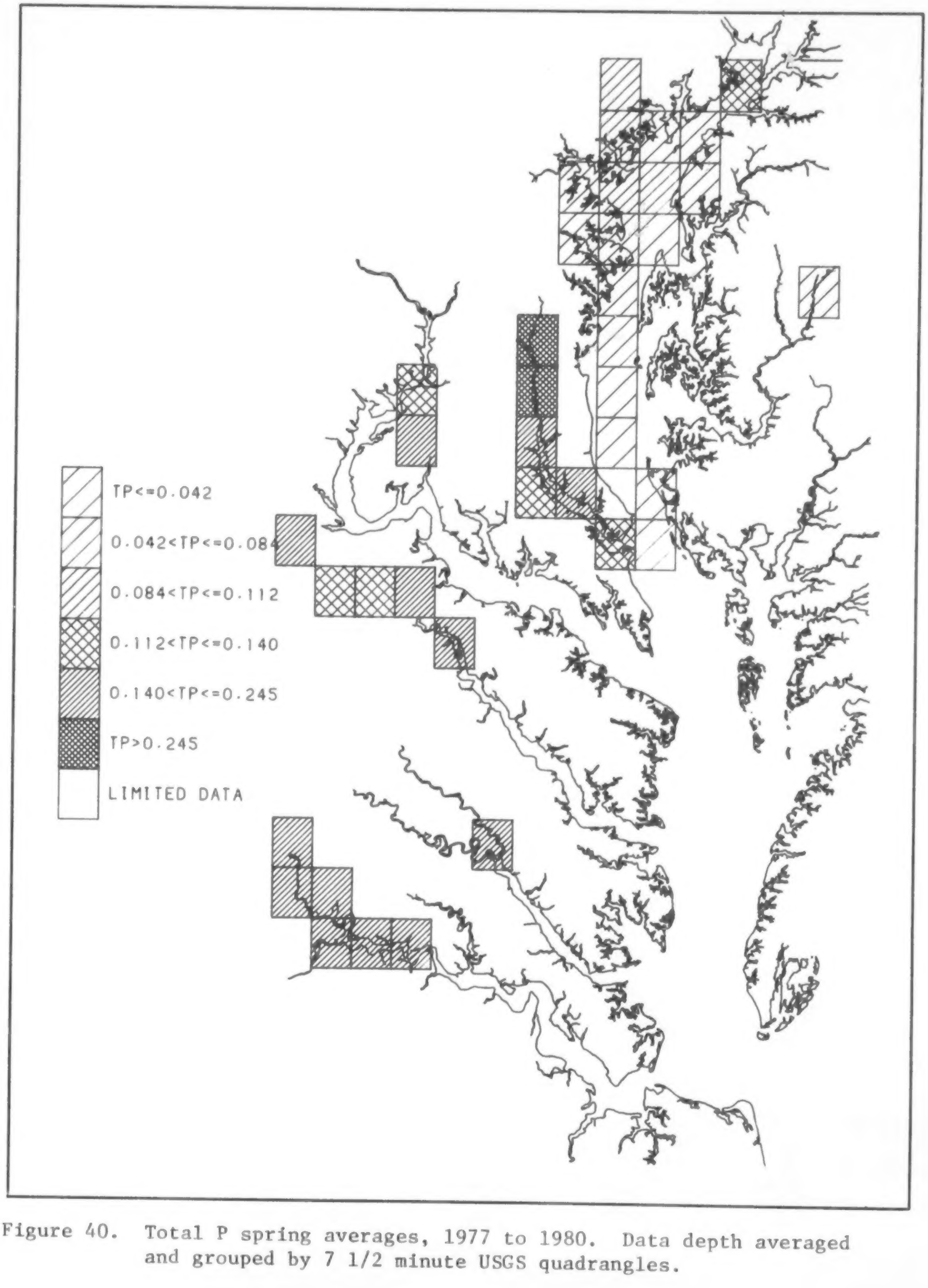
TP<=0.042
0.042<TP<=0.084
0.084<TP<=0.112
0.112<TP<=0.140
0.140<TP<=0.245
TP>0.245
LIMITED DATA

Figure 40. Total P spring averages, 1977 to 1980. Data depth averaged and grouped by 7 1/2 minute USGS quadrangles.

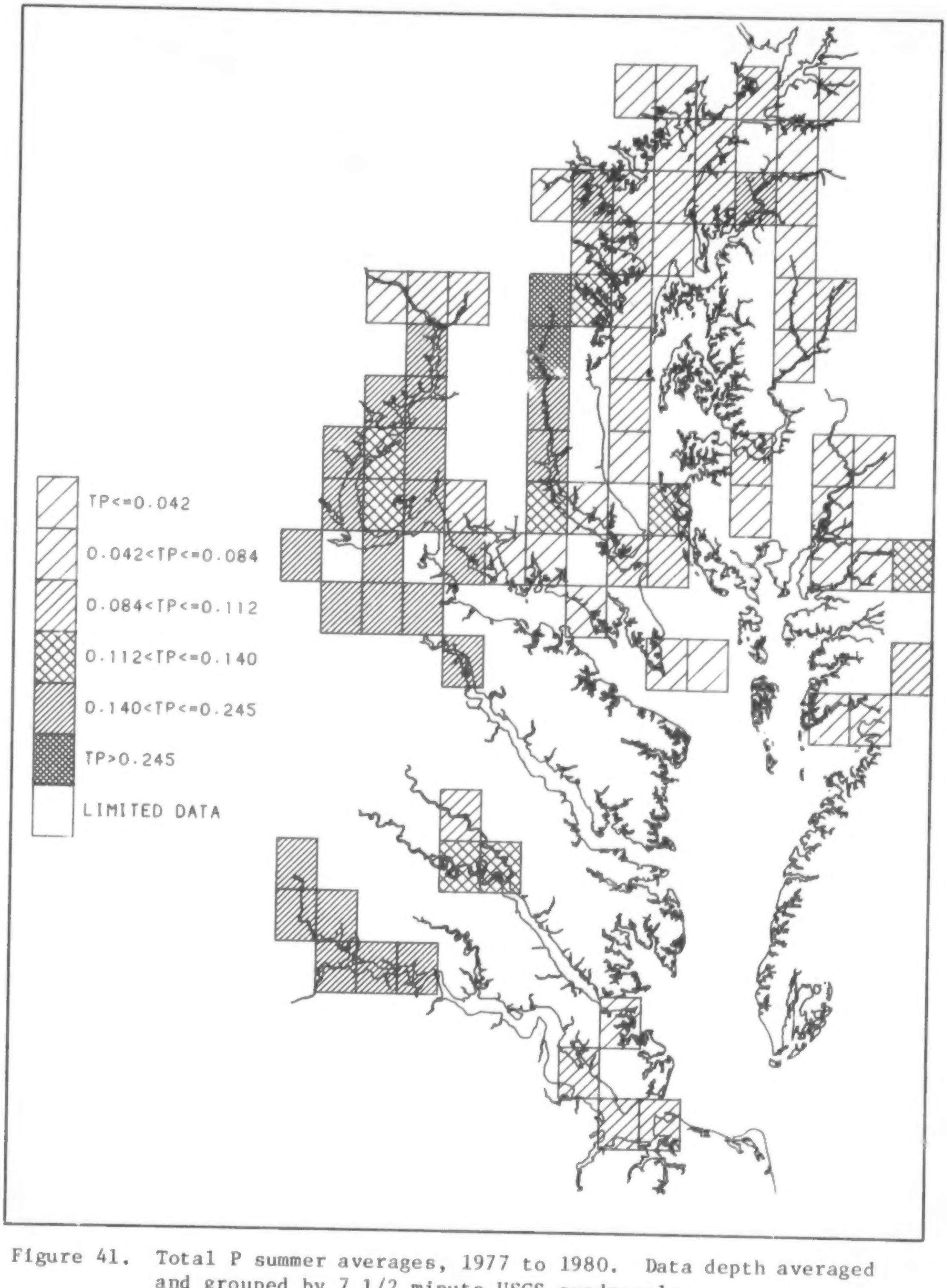
TP<=0.042
0.042<TP<=0.084
0.084<TP<=0.112
0.112<TP<=0.140
0.140<TP<=0.245
TP>0.245
LIMITED DATA

Figure 41. Total P summer averages, 1977 to 1980. Data depth averaged and grouped by 7 1/2 minute USGS quadrangles.

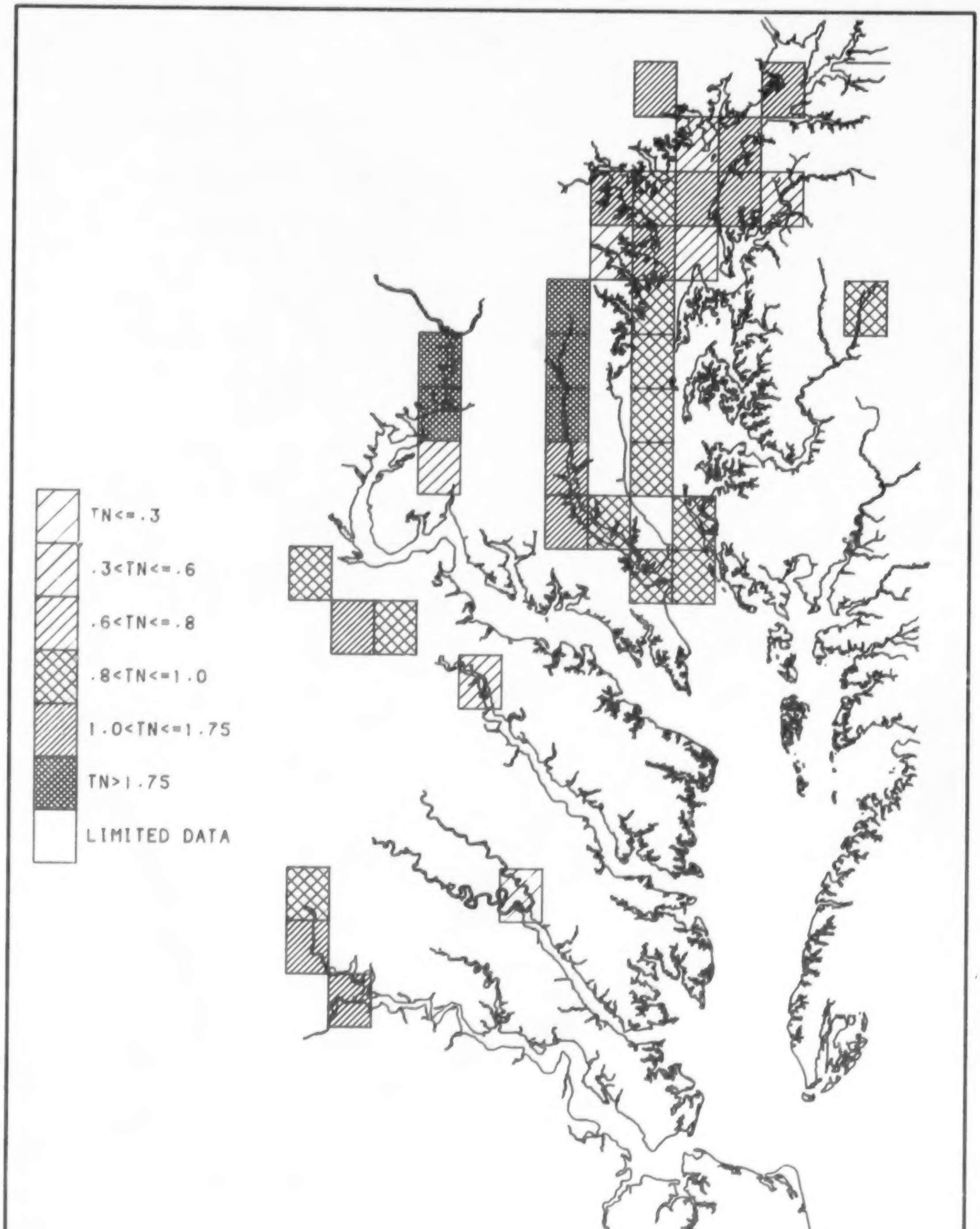
TN<=.3
.3<TN<=.6
.6<TN<=.8
.8<TN<=1.0
1.0<TN<=1.75
TN>1.75
LIMITED DATA

Figure 42. Total nitrogen annual average, 1977 to 1980. Data depth averaged and grouped by 7 1/2 minute USGS quadrangles.

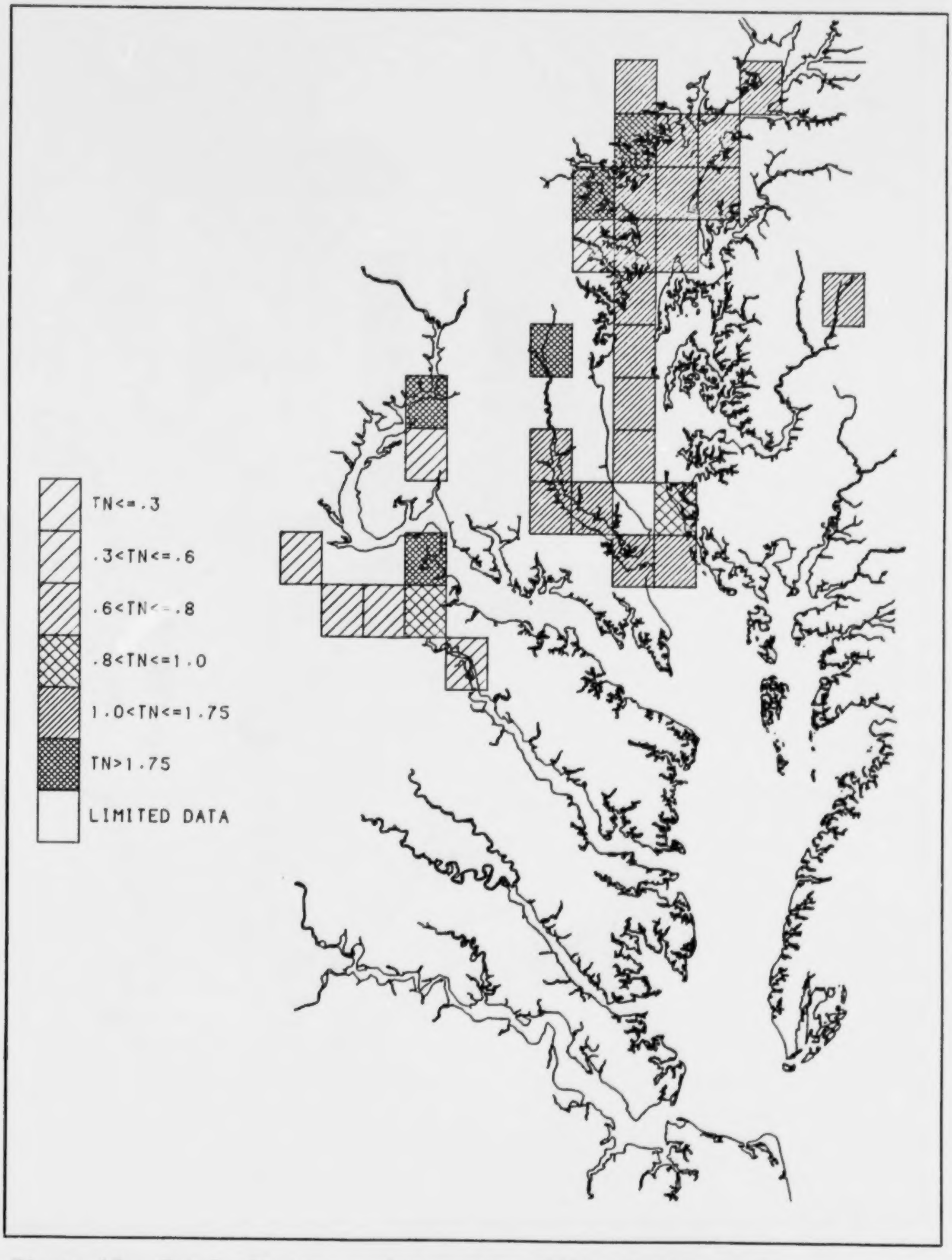
TN<=.3
.3<TN<=.6
.6<TN<=.8
.8<TN<=1.0
1.0<TN<=1.75
TN>1.75
LIMITED DATA

Figure 43. Total nitrogen spring average, 1977 to 1980. Data are depth averaged and grouped by USGS 7½ - minute quadrangles.

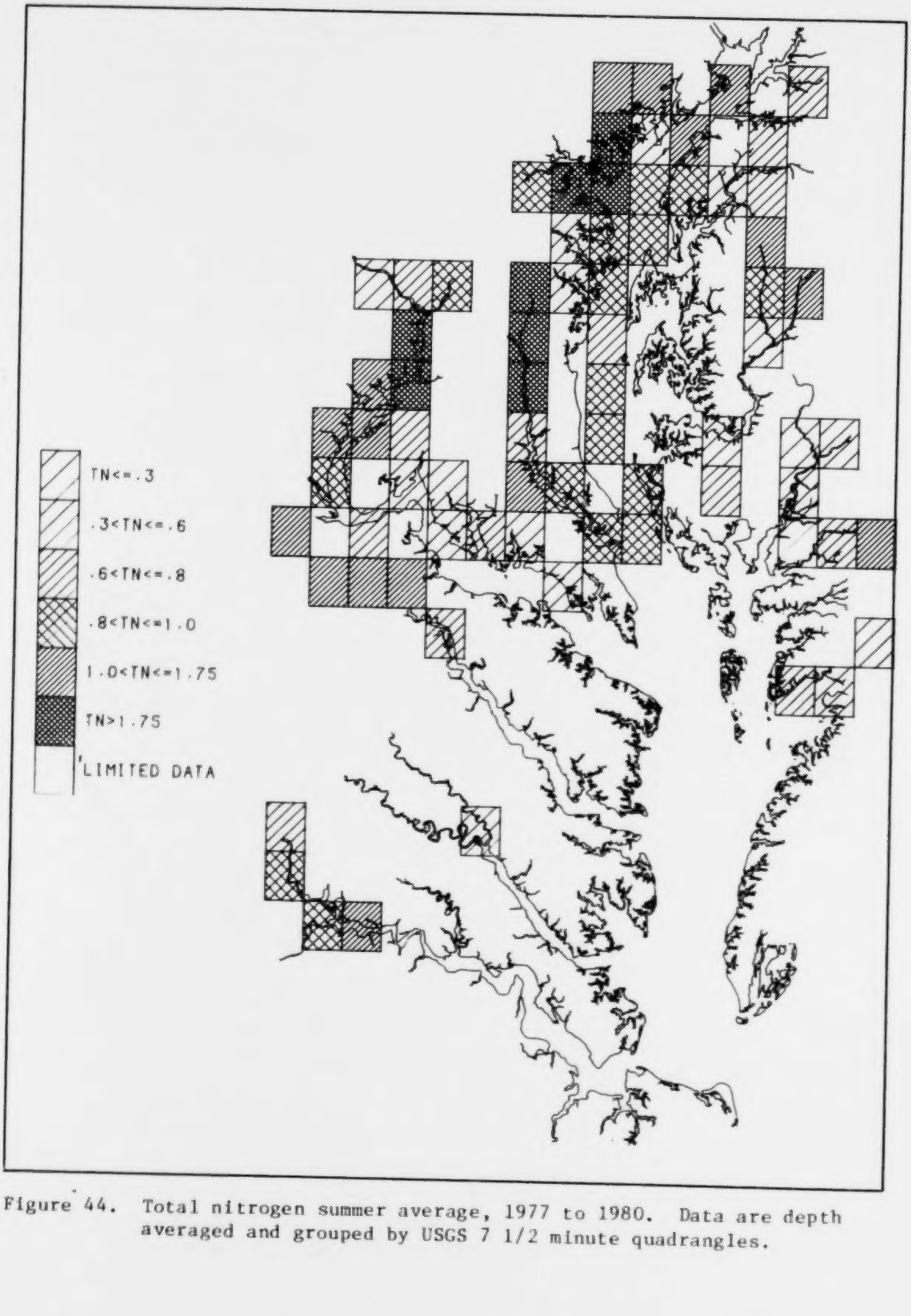
TN<=.3
.3<TN<=.6
.6<TN<=.8
.8<TN<=1.0
1.0<TN<=1.75
TN>1.75
LIMITED DATA

Figure 44. Total nitrogen summer average, 1977 to 1980. Data are depth averaged and grouped by USGS 7 1/2 minute quadrangles.

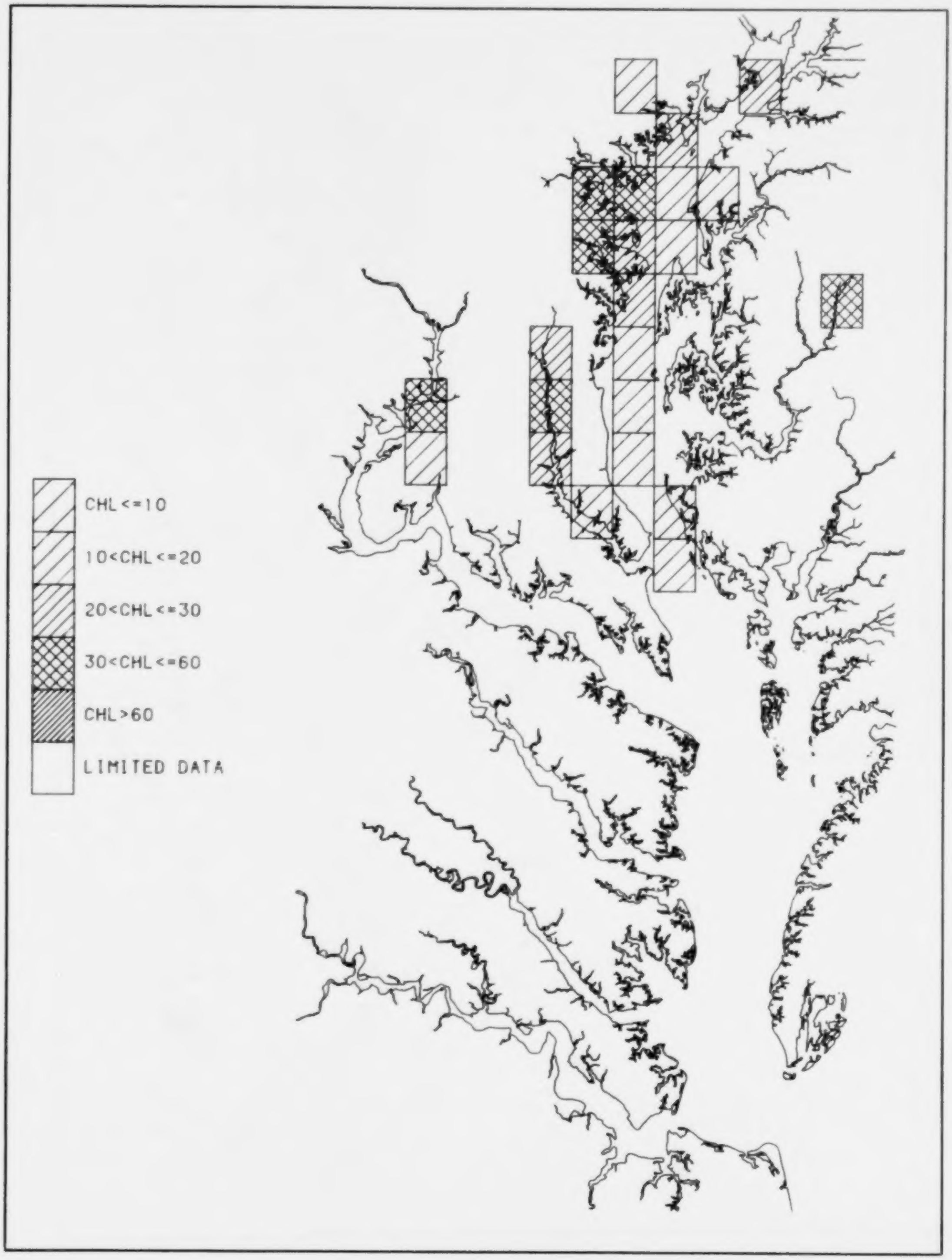
CHL<=10
10<CHL<=20
20<CHL<=30
30<CHL<=60
CHL>60
LIMITED DATA

Figure 45. Total chlorophyll annual average, 1977 to 1980. Data are surface averaged and grouped by USGS 7 1/2 minute quadrangles.

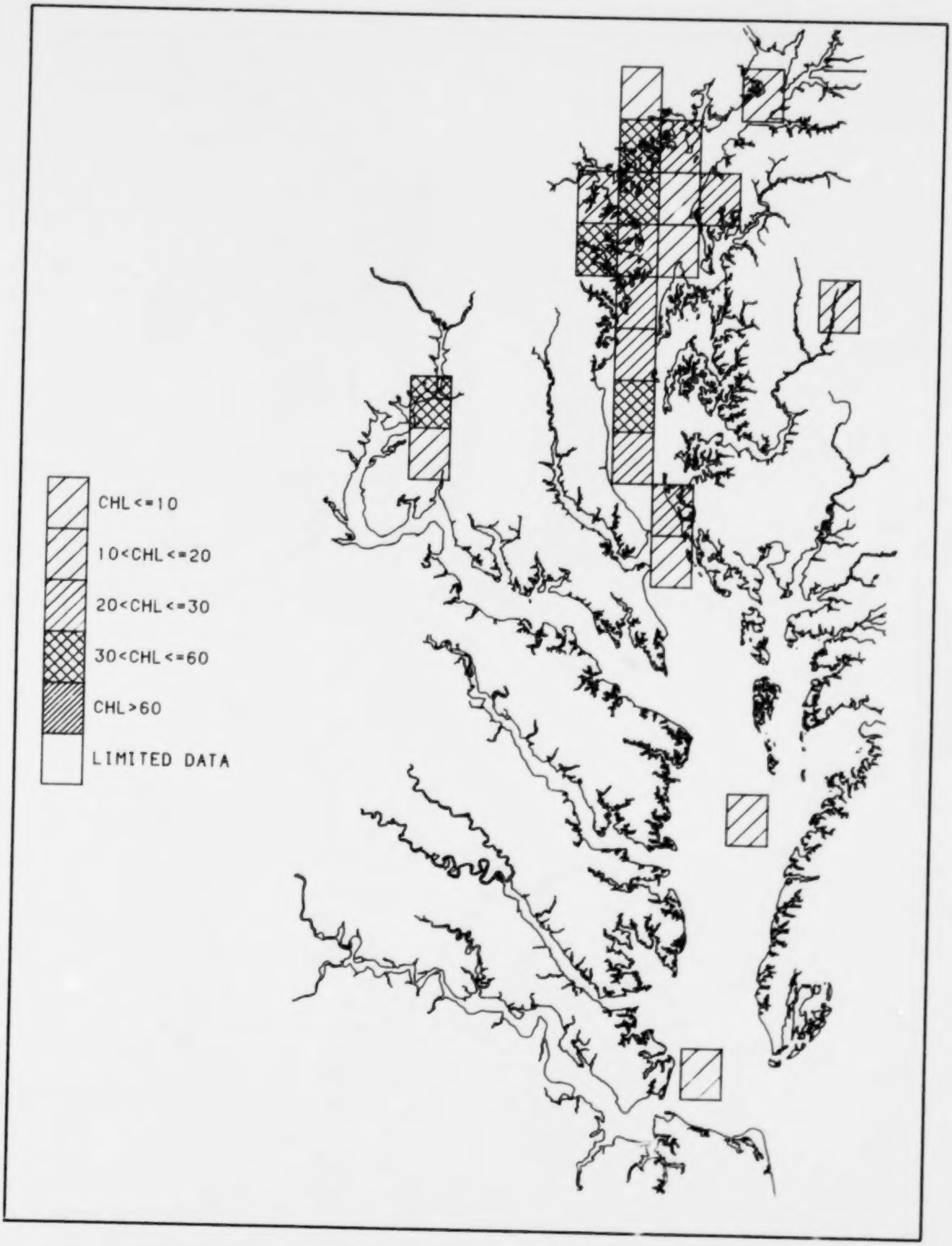
CHL<=10
10<CHL<=20
20<CHL<=30
30<CHL<=60
CHL>60
LIMITED DATA

Figure 46. Total chlorophyll spring average, 1977 to 1980. Data are surface averaged and group by USGS 7 1/2 minute quadrangles.

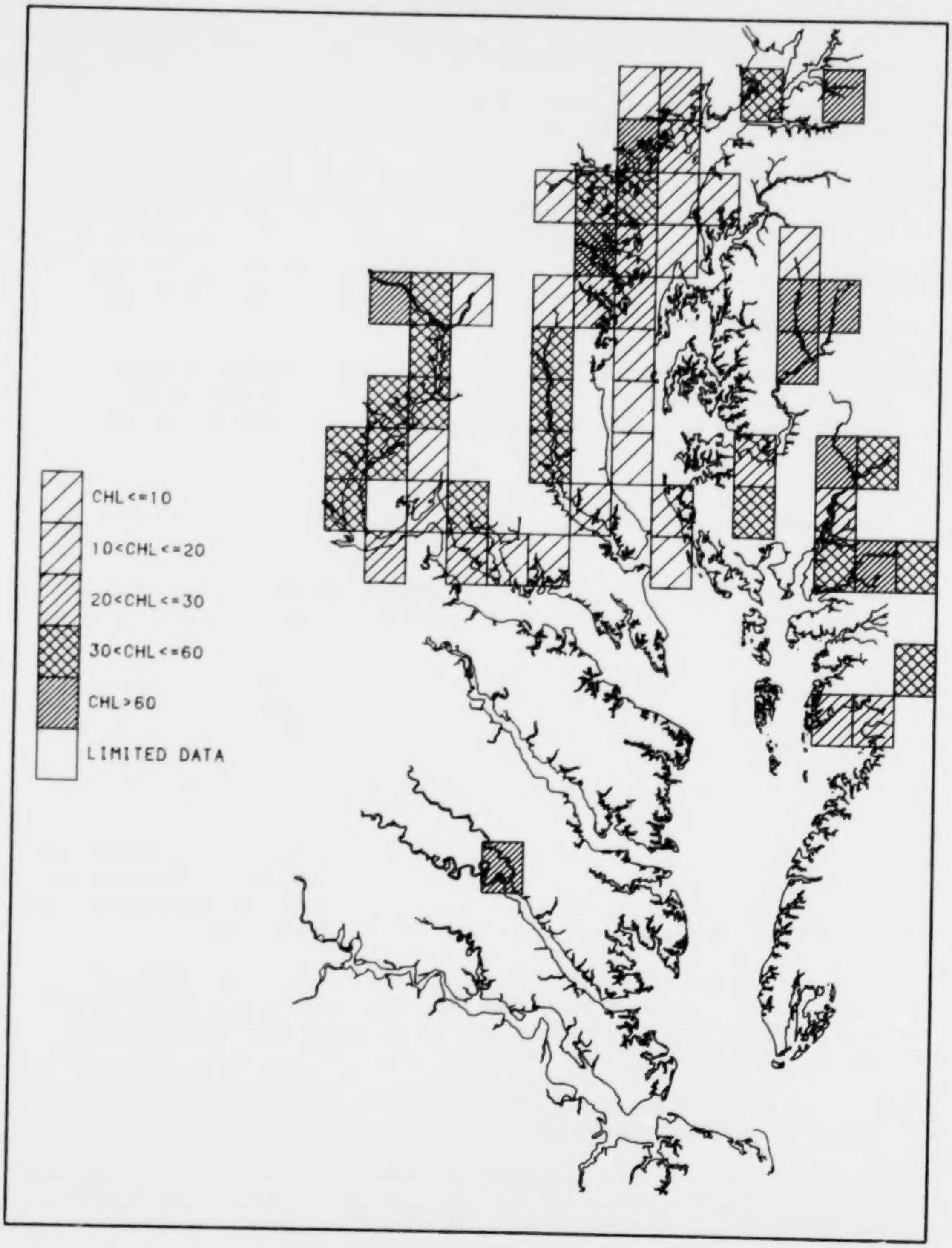
CHL<=10
10<CHL<=20
20<CHL<=30
30<CHL<=60
CHL>60
LIMITED DATA

Figure 47. Total chlorophyll summer average, 1977 to 1980. Data are surface averaged anb grouped by USGS 7 1/2 minute quadrangles.

SECTION 9

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SECTION 1

LIFE CYCLES OF MAJOR SPECIES

GENERAL FISHERY INFORMATION

ENVIRONMENTAL CONDITIONS FOR SPAWNING AND DEVELOPMENT OF SELECT SPECIES

ECOLOGY OF WETLANDS FOUND IN THE CHEAPEAKE BAY AREA

ECOLOGY OF SUBMERGED AQUATIC VEGETATION FOUND IN THE CHESAPEAKE BAY AREA

TABLE 1a. ENVIRONMENTAL TOLERANCES OF ALOSA AESTIVALIS (BLUEBACK HERRING) CANADIAN MARITIMES TO ST. JOHN'S RIVER, FL

LIFE STAGE	HABITAT REQUIREMENTS	FOOD AND FEEDING FACTORS	GROWTH & DEVELOPMENT FACTORS	BEHAVIOR	PREDATORS AND COMPETITORS	SELECTED REFERENCES
Eggs	Tidal-fresh and low-brackish water. Eggs are found in streams and rivers with swift currents and sandy or rocky substrate.	Not applicable	No information	Not applicable	No information	Burbidge 1974 Hudson and Hardy 1974 Jones et al. 1978 Lippson et al. 1979 Domermuth and Reed 1980 Raney and Massmann 1953
Larvae	Tidal-fresh and brackish water. Larvae are found in tributary streams and upper portions of rivers. Optimum salinity 0-5 ppt.	- copepods	Growth occurs during warm temperatures.	Interspecific competition with Bay anchovy in brackish water causes larvae to select food items other than the preferred type.	Compete with Bay anchovy. Prey of predatory fish (striped bass, white perch)	
Juvenile	Tidal-fresh and brackish water. Juveniles are found primarily in surface waters. Tolerate salinity 0-28 ppt. Optimum salinity 0-5 ppt.	Selective feeder during daylight. - copepods - copepodites - Bosmina spp. - macrozooplankton	Growth occurs during warm temperatures; rate of growth is more rapid than for alewives.	Young juveniles remain in nursery area until the fall, then undertake a seaward migration. Young may remain in the lower Bay during first or second winter.	Prey of predatory fish (striped bass, white perch, bluefish)	
Adult	0-34 ppt salinity. Adults enter the Bay to spawn in freshwater; return to the ocean after spawning.	- zooplankton - crustaceans - crustacean eggs - insects - fish eggs and larvae	Blueback herring mature in 3-4 yrs., and reach a maximum length of 38.0 cm.	Schooling herring occur in a narrow band of coastal water and move to the bottom during winter. Herring are anadromous, migrating into the Bay to spawn in spring.	Prey of predatory fish (striped bass, bluefish, weakfish) in fresh, brackish, & salt water. Target of a commercial & recreational fishery.	

TABLE 1b. ENVIRONMENTAL TOLERANCES OF ALOSA PSEUDOHARENGUS (ALEWIFE) NEWFOUNDLAND TO SOUTH CAROLINA

LIFE STAGE	HABITAT REQUIREMENTS	FOOD AND FEEDING FACTORS	GROWTH & DEVELOPMENT FACTORS	BEHAVIOR	PREDATORS AND COMPETITORS	SELECTED REFERENCES
Eggs	0-0.5 ppt salinity. Eggs are released in slow, shallow portions of creeks and rivers over detritus or sandy substrate.	Not applicable	Hatching period 6 days. Mean water temp. 60°F.	Not applicable	No information	Jones et al. 1978 Shea et al. 1980 Lippson et al. 1979 Hildebrand and Schroeder 1928
Larvae	0-3 ppt salinity. Larvae remain in vicinity of spawning area at depths less than 3 m.	- rotifers - copepod nauplii	No information	Form schools within 1-2 days after hatching.	Prey of predatory fish (white perch and striped bass)	
Juvenile	Tolerate salinity 0-34 ppt. Optimum salinity 0.5-5 ppt. Young juveniles are found in nursery areas from shore to shore; as the fish grow, there is a slow downstream movement.	- copepods - mysid shrimp	Grow very rapidly, possibly due to entering salt water, average 105 mm.	Young juveniles migrate toward the ocean in the fall, some overwinter in deep areas of the Bay.	Prey of predatory fish (bluefish, striped bass, white perch)	
Adult	0-34 ppt salinity. Adults enter the Bay to spawn in freshwater and return to ocean by mid-summer.	Mid-water feeder - copepods - young fish - zooplankton - mysids	Alewife mature in 3-4 yrs., measuring an average 25.0-30.0 cm in length.	Schooling alewife show regular anadromous Alosid coastal movements. Alewife are anadromous, migrating into the Bay to spawn in spring.	Prey of predatory fish (striped bass, bluefish, weakfish). In fresh, brackish, and salt water. Target of commercial and recreational fishery.	

TABLE 1c. ENVIRONMENTAL TOLERANCES OF *ALOSA SAPIDISSIMA* (AMERICAN SHAD) GULF OF ST. LAWRENCE TO FLORIDA

LIFE STAGE	HABITAT REQUIREMENTS	FOOD AND FEEDING FACTORS	GROWTH & DEVELOPMENT FACTORS	BEHAVIOR	PREDATORS AND COMPETITORS	SELECTED REFERENCES
Eggs	0-0.5 ppt salinity. Streams and rivers with swift currents and sandy or rocky substrate.	Not applicable	Temperatures above 21°C and low D.O. levels decrease hatching success.	Not applicable	No information	Hildebrand and Schroeder 1928 Shea et al. 1980
Larvae	Optimum salinity 0-5 ppt. Larvae are found at depths greater than 3 m.	No information	At D.O. levels of 5 ppm, some stress and mortality occurs; at D.O. levels of 4 ppm, high mortality may occur.	No information	Preyed upon by top predatory species (striped bass, bluefish, white perch, other herring spp.)	Domermuth and Reed 1980 Lippson et al. 1979 Ellis et al. 1947
Juvenile	Tolerate salinity 0.5-12 ppt. Optimum salinity 5-12 ppt. Young juveniles gradually move into more saline waters.	Feed at or beneath surface - daphnid cladocerans - bosminid cladocerans - other cladoceran spp. - copepods	Young grow rapidly during the first summer.	Juveniles remain in natal streams and rivers until the fall, then undertake a seaward migration. Some remain in the lower Bay during the first winter.	Competition with species such as alewife or blueback herring influences location of feeding fish and selection of prey. Prey of top predatory species.	
Adult	Tolerate salinity 0-34 ppt. Adults enter the Bay to spawn in freshwater or on flats in tidal waters and return to ocean after spawning.	Feed in surface layer - copepods - small fish - planktivorous crustaceans - insects	Growth rate decreases after 3 years of age. Reach sexual maturity in 4-5 years.	Shad are anadromous, migrating into the Bay to spawn in spring. Nests are built, but no parental care is given to eggs.	Prey of top predatory fish (bluefish, striped bass). Target of a commercial and recreational fishery.	

TABLE 1d. ENVIRONMENTAL TOLERANCES OF BREVOORTIA TYRANNUS (ATLANTIC MENHADEN) NOVA SCOTIA TO GULF OF MEXICO

LIFE STAGE	HABITAT REQUIREMENTS	FOOD AND FEEDING FACTORS	GROWTH & DEVELOPMENT FACTORS	BEHAVIOR	PREDATORS AND COMPETITORS	SELECTED REFERENCES
Eggs	Eggs are released in the ocean, probably not far (as far as 64 km) from the mouth of the Bay.	Not applicable	No information	Not applicable	No information	Pristas and Willis 1973 Shea et al. 1980 June and Carlson 1971 Durbin and Durbin 1975 Lippson et al. 1979
Larvae	Early larvae tolerate 18-34 ppt salinity. Optimum salinity 25-34 ppt. Later they concentrate in tidal-fresh to low-brackish waters (0-3 ppt salinity).	Sight-selective feeders - copepods size of fish influences size of copepods taken.	No information	Larvae enter the Bay in spring when they are about 10-30 mm long; may reach nursery areas in larval or juvenile stage.	No information	
Juvenile	Tolerate salinity 0-34 ppt. Optimum salinity 0-15 ppt. Younger fish concentrate in tidal-fresh to low-brackish waters.	Filter feeder - phytoplankton	No information	Young-of-the-year juveniles remain in the Bay during summer; may leave in fall or overwinter in Bay.	Prey of top predatory fish including bluefish and striped bass.	
Adult	Tolerate salinity 1-36 ppt. Concentrate in areas of 5-18 ppt salinity where food patches occur. One- and two-year-old adults utilize the Bay; older fish remain off the coast.	Filter feeder - zooplankton - larger phytoplankton - longer chains of chain-forming diatoms. Feeding behavior is linked to food density and particle size.	Some fish may reach maturity in one year; all fish are mature by age 3. Maximum length around 47.0 cm.	Schooling marine fish enter the Bay in spring to feed; most migrate seaward in the fall, though some may overwinter in in the lower Bay.	Prey of top predatory fish including bluefish and striped bass. Target of a commercial fishery.	

TABLE 1c. ENVIRONMENTAL TOLERANCES OF *CALLINECTES SAPIDUS* (BLUE CRAB) NEW JERSEY TO FLORIDA

LIFE STAGE	HABITAT REQUIREMENTS	FOOD AND FEEDING FACTORS	GROWTH & DEVELOPMENT FACTORS	BEHAVIOR	PREDATORS AND COMPETITORS	SELECTED REFERENCES
Eggs	Hatch at salinities of 10.3-32.6 ppt; optimum salinities for hatch are 23-30 ppt. Females carry the eggs until hatch occurs.	Not applicable	Salinity affects hatching success.	Not applicable	No information	Van Engel et al. 1973 Shea et al. 1980 Sulkin 1975 Van Engel 1958 Sandoz and Rogers 1944 Lippson 1971 Lippson et al. 1979
Zoeae	Tolerate salinities of 15.8-32.3 ppt; optimum salinities are 21-28 ppt. Zoeae are found in the upper surface water.	- rotifers - Nauplii larvae - sea urchin larvae - polychaete larvae	Zoeae molt at least three times, with the final mold producing a megalops. Molting is affected by salinity, temperature, larval concentrations, and light intensity.	Zoeae show an attraction to light.	No information	
Megalops	Optimum salinities of 20-35 ppt. Megalops may be found in surface waters or on the bottom.	Omnivorous - plants - fish and shellfish pieces - detritus Availability of prey affects diet.	Salinity and temperature affect the duration of the megalops stage. Megalops metamorphose into a small juvenile crab.	Megalops and juveniles move into the Bay through the entrainment in bottom waters, beginning in fall. In winter, young crabs cease migrations and burrow into channel bottoms.	No information	
Juveniles and Adults	Juveniles concentrate in brackish water with salinities less than 20 ppt. Adult males concentrate in salinities of 3-15 ppt. Females concentrate in salinities of 10-28+ ppt.	- benthic organisms - small fish - plants - shellfish - small crustaceans - detritus Availability of prey affects diet.	Crabs reach sexual maturity in 12-20 months depending on timing of hatch. Growth occurs by shedding the shell, and is regulated by water temperature.	In warm weather, juveniles move inshore. When temperatures drop, juveniles move to channel areas to overwinter in semi-hibernation. Adults have similar movement patterns.	- predatory fish such as striped bass and bluefish - birds such as herons and herring gulls - a commercial and recreational fishery	

TABLE II. ENVIRONMENTAL TOLERANCES OF CRASSOSTREA VIRGINICA (AMERICAN OYSTER) NEW ENGLAND TO GULF COAST

LIFE STAGE	HABITAT REQUIREMENTS	FOOD AND FEEDING FACTORS	GROWTH & DEVELOPMENT FACTORS	BEHAVIOR	PREDATORS AND COMPETITORS	SELECTED REFERENCES
Eggs	Optimum salinity of 22.5 ppt; below 10 ppt, survival is poor. Pelagic eggs released in open water.	Not applicable	Turbidity levels of 125 mg L^{-1} or more reduce development and survival of eggs.	Not applicable	No information	Galtsoff 1964 Haven and Morales-Alamo 1970 Korringa 1952 Davis and Calabrese 1964 Ukeles 1971 Andrews et al.1967 + 1968
Larvae	Optimal growth occurs at salinities of 12.5-25.0 ppt.	Filter feeder - phytoplankton - bacteria The size of food particles taken is a function of the mouth size.	Turbidity levels of 100 mg L^{-1} cause high larval mortality. Salinity, temperature and available food influence larval development.	Oyster larvae move within the estuary by entrainment in bottom waters. Larvae search for suitable substrate on which to attach in about two weeks. At setting, larvae metamorphose to spat.	Prey of planktonic-feeding fish and invertebrates.	
Juveniles (spat)	Salinity 5-35 ppt. Oysters are found in shallow water less than 10 meters deep.	Filter feeder - phytoplankton - bacteria - detritus	Spat exhibit rapid growth during the first year. Growth rates are affected by availability of food, salinity, and water temperature.	Oysters initially develop as males, yet by the second breeding season many change into females.	Competitors - boring sponges and clams - slipper shell - sea squirt - barnacles - spirochaetes - perforating algae Predators - oyster drills - blue crabs - starfish - birds - commercial fishery Diseases - Perkinsus marinus (Dermo) - Minchinia nelsoni (MSX)	
Adults	Optimum survival of oysters occurs on hard substrate such as rocks, pilings, and oyster shells in the intertidal and sub-tidal zones.	Filter feed on 1-12 micron prey - phytoplankton - bacteria - detritus Turbidity and low temperatures influence feeding and digestion.	Growth is affected by substrate type, salinity, temperature, tidal flow, and crowding. Oysters reach sexual maturity during the second year of growth. [A few reach maturity at one year (Haven)]	Epibenthic with frequent alternation of sex. Form communities or "bars." Oyster distribution in higher salinity areas is restricted by predators and parasites.		

TABLE 1g. ENVIRONMENTAL TOLERANCES OF CYNOSCION REGALIS (WEAKFISH) MASSACHUSETTS TO FLORIDA

LIFE STAGE	HABITAT REQUIREMENTS	FOOD AND FEEDING FACTORS	GROWTH & DEVELOPMENT FACTORS	BEHAVIOR	PREDATORS AND COMPETITORS	SELECTED REFERENCES
Eggs	Tolerate salinities of 5-34 ppt. Buoyant eggs are released in the nearshore and estuarine zones along the coast.	Not applicable	Eggs are susceptible to low D.O. levels and sudden changes in either salinity or temperature.	Not applicable	No information	Lippson et al. 1979 Daiber et al. 1976 Wilk 1978 McHugh 1978
Larvae	Tolerate salinities 12-31 ppt. Larvae remain in the general vicinity of spawning.	No information	Larvae cannot withstand sudden changes in either salinity or temperature; a 5°C change in temperature in either direction can be fatal.	No information	No information	
Juvenile	About 0-34 ppt salinity. Young-of-the-year fish move into low salinity areas over soft, muddy bottoms.	- shrimp - other crustacean spp. - bay anchovy - young menhaden - other small fish	Weakfish grow most rapidly during their first year, reaching an average length of 19 cm.	Young juveniles move into low salinity areas for the summer; they migrate to the coast in fall, move offshore and south in winter. Begin schooling as pre-adults.	Preyed upon by bluefish, striped bass, and large weakfish.	
Adult	Tolerate salinities of 10-34 ppt. Adults remain in the lower portion of the Bay.	Primarily piscivorous - menhaden - herring spp. - bay anchovy - silversides - crustaceans - annelids	Weakfish are sexually mature in 2-3 years, and reach an average length of about 50.0 cm.	Adults school, arrive in Bay in spring, leave by late fall and head south and offshore for the winter; return north to inshore areas in spring.	Preyed upon by bluefish and striped bass. The target of a commercial and recreational fishery.	

TABLE 1h. ENVIRONMENTAL TOLERANCES OF CYNOSCION NEBULOSUS (SPOTTED SEATROUT) DELAWARE TO MEXICO

LIFE STAGE	HABITAT REQUIREMENTS	FOOD AND FEEDING FACTORS	GROWTH & DEVELOPMENT FACTORS	BEHAVIOR	PREDATORS AND COMPETITORS	SELECTED REFERENCES
Eggs	Spawning occurs at salinities of 30-35 ppt. Hatched in 40 hrs at 25°C. Eggs reported as both demersal and pelagic, released in deeper channels and holes adjacent to grassy bays and flats.	Not applicable	Eggs are susceptible to low D.O. and sudden changes in salinity or temperature.	Not applicable	No information	Tabb 1961 Arnold et al. 1978 Fable et al. 1978 Idyll and Fahy 1975 Lorio and Perret 1980
Larvae	Growth of larvae is rapid, about 4.5 mm in 15 days after hatching. Young fish spend their juvenile life in vegetated flats, moving to deeper water in winter.	Very small invertebrates, including copepods, mysid shrimp, and post-larval penaeid shrimp.	Highly sensitive to changes in temperature. Winter-time cold shock and high temperature changes cause kills.	Tend to remain close to site of spawning in grassy flats.	No information	
Juvenile	Fish larger than 2 inches show a tendency to congregate in schools. Remain in grassy, shallow water flats until colder weather causes them to move to deeper water.	As the trout grow, diet changes to include larger portions of caridean shrimp and then to penaeid shrimp.	Females grow faster than males but males attain sexual maturity at a smaller size. Growth is rapid in first year with lengths of 13 cm attained by the first winter and 25 cm their second winter.	Start to school as young fish but remain in general area of nursery grounds until cold weather causes them to move to deeper water.	Reported as highly cannibalistic in the post-larval stage.	

(continued)

TABLE 16. (CONTINUED)

LIFE STAGE	HABITAT REQUIREMENTS	FOOD AND FEEDING FACTORS	GROWTH & DEVELOPMENT FACTORS	BEHAVIOR	PREDATORS AND COMPETITORS	SELECTED REFERENCES
Adult	While tagging studies show that some seatrout travel as much as 315 miles, most studies show that few fish leave their natal estuary. *C. nebulosus* occupies a more southern, warmer water habitat than does *C. regalis*.	Listed as the top carnivore in most estuarine communities. As an adult, will eat all other fish of a smaller size as well as shrimp and small crabs.	Longevity indicated to be 8 to 9 years of age. Generally mature at one to three years with 50% sexually mature by end of second year (25 cm in length). All fish appeared to have spawned by age three. A 1978 report cites the largest sea trout caught was 16 pounds.	Movement patterns have been traced to the presence or absence of penaeid shrimp. Seasonal movements correspond to water temperature and spawning season.	A top predator that would be in competition with other predators such as bluefish and striped bass. Target of both commercial and recreational fisheries.	

TABLE 11. ENVIRONMENTAL TOLERANCES OF ICTALURUS CATUS (WHITE CATFISH) NEW YORK TO FLORIDA

LIFE STAGE	HABITAT REQUIREMENTS	FOOD AND FEEDING FACTORS	GROWTH & DEVELOPMENT FACTORS	BEHAVIOR	PREDATORS AND COMPETITORS	SELECTED REFERENCES
Egg	Freshwater Eggs deposited in nests built near sand or gravel banks in still or running water.	Not applicable	Eggs need to be aerated.	Not applicable	No information	Jones et al. 1978 Lippson et al. 1979
Larvae	In freshwater, may move into tidal water.	No information	Yolk sac larvae bypass larval stage, developing directly to juvenile stage.	No information	No information	Daiber et al. 1976
Juvenile	No information	No information	Growth continues at 11 ppt salinity or less.	Remain in schools until end of first summer; initially guarded by parents.	No information	(Kendall and Schwartz 1968
Adult	Maximum salinity of 14.5 ppt Widespread in Bay. Prefer heavily silted bottom. Inhabit river channels and streams with slow current, ponds, and lakes.	Omnivorous, solitary, bottom feeder -plant material -small fish -clams and snails -worms -insects -dead material	Fish mature in one to two years. Maximum length 61.0 cm.	Stay in waters greater than 3 m, overwinter in deeper water (15 m), move upstream to spawn in freshwater. Males guard and aerate egg masses.	No information	

TABLE 13. ENVIRONMENTAL TOLERANCES OF ICTALURUS NEBULOSUS (BROWN BULLHEAD) SOUTHERN CANADA TO SOUTHERN FLORIDA

LIFE STAGE	HABITAT REQUIREMENTS	FOOD AND FEEDING FACTORS	GROWTH & DEVEL-OPMENT FACTORS	BEHAVIOR	PREDATORS AND COMPETITORS	SELECTED REFERENCES
Egg	Freshwater. Eggs deposited in nests in sand or gravel at depths of several inches to several feet.	Not applicable	Eggs exposed to direct sunlight produce poor hatches. Eggs need to be agitated.	Not applicable	No information	Jones et al. 1978 Lippson et al. 1979 Dalber et al. 1976
Larvae	Freshwater. Found at bottom.	No information	Yolk-sac larvae bypass larval stage, developing directly to juvenile stage.	Grouped in a tight mass at bottom.	No information	
Juvenile	Found among vegetation or other cover over muddy bottoms.	No information	No information	Young juveniles herded in schools by parents; may remain in schools throughout the first summer.	No information	
Adult	Adults are widespread throughout most of the Bay area, occurring in channels and shallow, muddy water around aquatic vegetation. Maximum salinity 10 ppt.	Omnivorous, solitary bottom feeder - plant material - small fish - clams and snails - worms - insects - dead material	Mature at 3 years. Maximum length around 50.8 cm.	A schooling bottom species that is active primarily at night. Fish may burrow in soft sediments. Adults attend eggs and orally agitate.	No information	

TABLE 1k. ENVIRONMENTAL TOLERANCES OF *ICTALURUS PUNCTATUS* (CHANNEL CATFISH) HUDSON BAY REGION TO NORTHERN MEXICO

LIFE STAGE	HABITAT REQUIREMENTS	FOOD AND FEEDING FACTORS	GROWTH & DEVELOPMENT FACTORS	BEHAVIOR	PREDATORS AND COMPETITORS	SELECTED REFERENCES
Egg	Eggs 1 to 2 days old tolerate salinity to 10 ppt; 3 days and older 16 ppt.	Not applicable	No information	Not applicable	No information	Jones et al. 1978 Lippson et al. 1979 Daiber et al. 1976
Larvae	Tolerate salinities up to 8 ppt.	No information	Abnormal development occurs at temperatures above 35°C. Yolk-sac larvae bypass larval stage, and develop to juvenile stage.	Larvae guarded by male first few days after hatching.	No information	
Juvenile	Tolerate salinities up to 11-12 ppt.	Feed at surface	Growth continues at 11 ppt salinity or less.	Remain in schools up to several weeks. Show strong schooling and hiding tendencies in first year.	No information	
Adult	Maximum salinity of 21.0 ppt, but prefer less than 1.7 ppt. Restricted distribution in Bay. - deeper channels of large rivers with sluggish or swift current.	Omnivorous, solitary, bottom feeder - plant material - small fish - clams and snails - worms - insects - dead material	Mature in 2 to 9 years. Maximum length around 120.2 cm.	Males construct nests and guard eggs.	No information	

TABLE I 1. ENVIRONMENTAL TOLERANCES OF LEIOSTOMUS XANTHURUS (SPOT) MASSACHUSETTS TO FLORIDA

LIFE STAGE	HABITAT REQUIREMENTS	FOOD AND FEEDING FACTORS	GROWTH & DEVELOPMENT FACTORS	BEHAVIOR	PREDATORS AND COMPETITORS	SELECTED REFERENCES
Egg	Eggs are released over the continental shelf.	Not applicable	No information	Not applicable	Jellyfish, such as the sea walnut (*Mnemiopsis leidyi*), predatory marine fish.	Hudson and Hardy 197 Shea et al. 1980 Lippson et al. 1979 Thomas 1971 Chao and Musick 1977 Peters and Kjelson 1975
Larvae	Tolerate salinity 0-35 ppt. Optimum salinity 0-5 ppt in the estuary.	Sight-selective feeder - planktonic copepods	No information	No information	Prey of predatory fish and birds	
Juvenile	Tolerate salinity 0-34.2 ppt. Post-larvae and young fish concentrate at salinities of 0.5-5.0 ppt; during years of high population density, young may move into freshwater. Prefer muddy substrate.	Bottom feeder - benthic harpacticoid copepods - annelids - plant material	Growth during first summer is rapid; juveniles may measure 13 cm by late fall.	Post-larvae are carried into the Bay in April through entrainment in bottom waters. School along shore during summer. Young move downstream as they grow.	Same as above	
Adult	8-34 ppt salinity. Occur at depths greater than 1 m over soft muddy bottom; larger fish prefer channel waters.	Bottom feeder - burrowing polychaetes - annelids - small crustaceans - molluscs - macrozooplankton	Reach sexual maturity by the third year; maximum length around 33-35 cm.	Adults enter the Bay in April and May, leave for spawning grounds offshore from Aug. through Nov.	Prey of large gamefish (striped bass), sharks, and the target of recreational and commercial fisheries.	

TABLE 1m. ENVIRONMENTAL TOLERANCES OF MERCENARIA MERCENARIA (HARD CLAM) NOVA SCOTIA TO YUCATAN

LIFE STAGE	HABITAT REQUIREMENTS	FOOD AND FEEDING FACTORS	GROWTH & DEVELOPMENT FACTORS	BEHAVIOR	PREDATORS AND COMPETITORS	SELECTED REFERENCES
Eggs	Tolerate 20-35 ppt salinity, prefer 26.5-27.5 ppt.	Not applicable	Salinity affects egg development.	Eggs are carried on currents in the Bay.	No information	Lippson 1973 Daiber et al. 1976
Larvae	Salinities greater than 17.5 ppt. Larvae are pelagic, found in the surface waters.	No information	Larval development is affected by salinity, temperature, turbidity, and circulation patterns.	Larvae are initially pelagic, but toward the end of this stage, they alternate between a planktonic and benthic existence.	Clam larvae are prey of other filter feeding organisms.	Shea et al. 1980 Castagna and Chanley 1973
Juvenile	Optimum salinity 24-28 ppt; survive salinities as low as 12.5 ppt.	Filter feeder - algae species - detritus	Growth rates vary with the type of substrate used; faster growth occurs in coarser sediments.	Young clams have bisexual gonads, usually dominated by male characteristics. After the first spawning season, about 50% of the juveniles become female.	Predators include - oyster drills - blue crabs - moon snails - conchs - horseshoe crabs - sea stars - puffers - waterfowl	
Adult	Salinities greater than 15 ppt. Hard clams occur in subtidal or intertidal waters with solid substrate (shell or rock).	Filter feeder - algae species	Large clams measure 12-13 cm in length.	Adults spawn during neap tides; spawning may be both thermally and chemically stimulated.	- cow nosed rays - drum fish - recreational and commercial fishery	

TABLE 1n. ENVIRONMENTAL TOLERANCES OF MICROPOGONIAS UNDULATUS (ATLANTIC CROAKER) CAPE COD, MA. TO FLORIDA

LIFE STAGE	HABITAT REQUIREMENTS	FOOD AND FEEDING FACTORS	GROWTH & DEVELOPMENT FACTORS	BEHAVIOR	PREDATORS AND COMPETITORS	SELECTED REFERENCES
Eggs	Eggs are released in the ocean near the mouth of the Bay from August through December.	Not applicable	No information	Not applicable	No information	Shea et al. 1980 Hildebrand and Schroeder 1928 Lippson et al. 1979 Stickney et al. 1975 Chao and Musick 1977 Haven 1957 Joseph 1972 Wallace 1940
Larvae	Larvae which enter the Bay in fall remain in channel waters at depths greater than 3 m; carried to the salt water interface.	No information	No information	Larvae begin entering the Bay in fall through entrainment in bottom waters.	No information	
Juvenile	Young juveniles are found in channel waters of 0-21 ppt salinity. Older fish tend to be down-river from the younger fish.	Juveniles less than 10 cm - harpacticoid copepods Older juveniles - polychaetes - crustaceans - fish - other invertebrates	No growth occurs during the winter season; young fish have been killed during intensive cold periods on the nursery grounds.	Yearling croaker leave in the fall.	Striped bass predation on overwintering juveniles may depress the population; juveniles also preyed on by bluefish.	
Adult	Tolerate salinity 0-40 ppt. Optimum salinity 10-34 ppt. Hard bottom at depths greater than 3 m.	- small crustaceans - annelids - molluscs - small fish	Croaker reach a maximum length of around 50 cm.	Croaker enter the Bay in spring, remaining in the lower estuary until fall, then they migrate back to sea. Water temperature influences croaker migrations.	Prey of top predatory species (striped bass and bluefish). The target of a commercial and recreational fishery.	

TABLE 1o. ENVIRONMENTAL TOLERANCES OF *MORONE AMERICANA* (WHITE PERCH) NOVA SCOTIA TO SOUTH CAROLINA

LIFE STAGE	HABITAT REQUIREMENTS	FOOD AND FEEDING FACTORS	GROWTH & DEVELOPMENT FACTORS	BEHAVIOR	PREDATORS AND COMPETITORS	SELECTED REFERENCES
Egg	Tolerate salinity 0-6 ppt. Eggs are released in tidal-fresh to low-brackish waters in shallows along the shore.	Not applicable	Suspended sediment levels about 1500 ppm increase incubation period.	Not applicable	No information	Shea et al. 1980 Lippson et al. 1979 Hildebrand and Schroeder 1928
Larvae	Tolerate salinity 0-8 ppt, prefer 0-1.5 ppt. Maximum depth 3.7 m. Larvae are found in shallow water over sand or gravel bars or mud bottom.	Sight-selective feeders - rotifers - cladocerans - copepods	Temperature and availability of rotifers affect development of yolk-sac larvae.	Remain in spawning area, settle to bottom. General downstream movement as larvae develop.	Compete with striped bass larvae in nursery areas. Preyed upon by fish (striped bass) and birds.	Hudson and Hardy 1974 Loos 1975 Mansueti 1961
Juvenile	Tolerate salinity 0-13 ppt, prefer 0-3 ppt. Found in shallow sluggish water over silt, mud, or vegetation; move to sandy shoals and beaches at night.	- copepods - cladocerans - insect larvae	Growth positively correlated with temperature and solar radiation. Growth influenced by population density.	Juveniles remain in nursery area at least until 20 mm long, may remain until 1 year old. Juveniles may form large schools.	Compete with striped bass juveniles. Preyed upon by fish (striped bass, bluefish) and birds.	
Adult	Tolerate salinity 0-30 ppt, prefer 4-18 ppt. In summer, concentrate near shoals, occasionally in channel areas. In winter, found in deeper water; move to channels during coldest periods.	Bottom oriented, piscivorous - smelt - yellow perch - young eels - young striped bass - insects - crustaceans	Growth rates decrease with age and high population density. Males mature in 2 years, females in 3.	Schooling adults are resident to the Bay. White perch are semi-anadromous, making spawning migrations upstream in spring.	Preyed on by larger fish (striped bass, bluefish). Also the target of a commercial and recreational fishery.	

TABLE 1p. ENVIRONMENTAL TOLERANCES OF *MORONE SAXATILIS* (STRIPED BASS) ST. LAWRENCE RIVER, CANADA TO ST. JOHN'S RIVER, FL

LIFE STAGE	HABITAT REQUIREMENTS	FOOD AND FEEDING FACTORS	GROWTH & DEVELOPMENT FACTORS	BEHAVIOR	PREDATORS AND COMPETITORS	SELECTED REFERENCES
Egg	Tolerate salinity 0-10 ppt. 1.5-3 ppt optimal. 1.0-2.0 m sec^{-1} optimum flow rate. Semi-buoyant eggs released in fresh to brackish water.	Not applicable	Salinity and temperature influence development.	Not applicable	Prey of white perch.	Setzler et al. 1980 Boynton et al. 1981 Beaven and Mihursky 1980 Hollis 1952 Doroshev 1970 O'Shea et al. 1980 Md. Dept. Nat. Res. 1981
Larvae	Tolerate salinity 0-15 ppt. 5-10 ppt optimal. 0.3-1.0 m sec^{-1} optimal flow rate. - open waters - at 13 mm, move inshore for first summer	Sight selective feeder - copepods - rotifers - cladocerans High prey concentrations necessary for successful first feeding.	Temperature and adequate food influence growth.	Positively phototrophic; newly-hatched larvae sink between swimming efforts; at 2-3 days of age, larvae can swim continuously.	Compete with white perch larvae in nursery area.	
Juvenile	Juveniles 50-100 mm. Tolerate salinity 0-35 ppt. Optimal 10-20 ppt. 0-1 m sec^{-1} optimal flow rate. - prefer sandy substrate but found over gravel bottoms as well in shallow waters.	Non-selective feeder - insect larvae - polychaetes - larval fish - amphipods - mysids	Temperature and population density influence growth.	Downstream movement of young-of-the-year fish. Yearlings school in rivers or move into lower estuary in summer.	Compete with white perch in nursery Prey of predatory fish, birds, mammals. Target of recreational and commercial fishery.	
Adult	Tolerate 0-35 ppt, usually in salinities greater than 12 ppt. Summer habitat includes high energy shorelines with a current. Overwinter in channels in estuary or offshore at depths below 6 m.	Piscivorous - alewife - blueback herring - white perch - spot - menhaden - bay anchovy - croaker	Temperature, age, population density, and oxygen levels influence growth.	Andromous, migrate to freshwater to spawn, return to lower estuary or ocean after spawning. Young females (2-3 yr) migrate along coast in summer with older fish.	Compete with bluefish, weakfish, and white perch. Target of commercial and recreational fishery.	

TABLE 1q. ENVIRONMENTAL TOLERANCES OF MYA ARENARIA (SOFT SHELL CLAM) LABRADOR TO NORTH CAROLINA

LIFE STAGE	HABITAT REQUIREMENTS	FOOD AND FEEDING FACTORS	GROWTH & DEVELOPMENT FACTORS	BEHAVIOR	PREDATORS AND COMPETITORS	SELECTED REFERENCES
Eggs	Eggs are released by sedentary adults in two spawning peaks, spring and fall.	Not applicable	No information	Not applicable	No information	Shea et al. 1980 Lucy 1977 Merrill and Tubiash 1970 Wallace et al. 1965 Castagna and Chanley 1973 Matthiessen 1960
Larvae	Minimum salinity for larval survival is 8 ppt.	Filter feeder - naked flagellates - other microscopic plankton spp.	Temperature influences larval development; at 10°C, larval development is slow.	After the planktonic larvae develop sufficiently, they metamorphose to adult form and settle to the bottom.	No information	
Juvenile	Juveniles occur over a broader depth range than adults.	Suspension feeder - phytoplankton - microzooplankton - bacteria - detritus	Juvenile clams are sensitive to salinity fluctuations.	Juveniles can move about by currents or by using the muscular foot. They establish a permanent burrow when one inch long.	Predators include: - blue crab - oyster drills - horseshoe crabs - cow-nosed rays - herring gulls - waterfowl - bottom feeding fish - commercial and recreational fisheries	
Adult	Tolerate salinity 3-35 ppt. Optimum 16-32 ppt. Clams occur on shallow sub-tidal beds in stable substrates at depths less than 6-10 m.	Suspension feeder - phytoplankton - microzooplankton - bacteria - detritus	Clams reach sexual maturity in one year. Growth is influenced by water currents, food supply, temperature, and sediment type.	Adults occur in deep, permanent burrows in shallow water.		

TABLE 1r. ENVIRONMENTAL TOLERANCES OF *PERCA FLAVESCENS* (YELLOW PERCH) EAST COAST RANGE OF NOVA SCOTIA TO SOUTH CAROLINA

LIFE STAGE	HABITAT REQUIREMENTS	FOOD AND FEEDING FACTORS	GROWTH & DEVELOPMENT FACTORS	BEHAVIOR	PREDATORS AND COMPETITORS	SELECTED REFERENCES
Egg	0-0.5 ppt salinity. Non-tidal and tidal-fresh water.	Not applicable	Low temperatures during spawning season cause an extended incubation period (2-3 wks); larvae more developed at hatch than other anadromous species.	Not applicable	No information	Setzler et al. 1980 Lippson et al. 1979 Auld and Schubel 1974 Daiber et al. 1976 Muncy 1962
Larvae	Tolerate salinity 0-2 ppt. Optimum 0-0.5 ppt. Shallow, freshwater; survival reduced when sediment concentrations exceed 500 mg L^{-1}.	- plankton	Salinities greater than 2 ppt interfere with larval development.	Larvae move downstream after hatching; concentrate near surface, form schools.	Preyed upon by white perch, striped bass, chain pickerel.	
Juvenile	0.5-10 ppt, concentrate at salinities of 5-7 ppt in summer. Found in vegetated areas near shore.	- small crustaceans - insects - worms - molluscs	Grows quickly during first year; growth rate decreases with age. Females have greater growth rate than males.	Initially concentrate at surface, become demersal at about 25 mm.	Preyed upon by fish such as white perch and striped bass, birds, mammals. Compete with white perch and striped bass.	
Adult	Tolerate 0-13 ppt salinity, prefer 5-7 ppt in summer. Prefer higher salinity, tidal waters with muddy substrate.	- bay anchovies - silversides - minnows - isopods - amphipods - snails - crustaceans	Males mature at 1 year of age, females mature at age 2 or 3; grow to 53 cm. Large populations cause stunting of adults.	Spring migration upstream to spawn; return downstream after spawning.	Competes with smaller fish and invertebrates for food. Preyed upon by birds (mergansers) and fish (gars and pikes). Target of commercial and recreational fishery.	

TABLE 1s. LIFE HISTORY OF *POMATOMUS SALTATRIX* (BLUEFISH) NOVA SCOTIA TO ARGENTINA

LIFE STAGE	HABITAT REQUIREMENTS	FOOD AND FEEDING FACTORS	GROWTH & DEVELOPMENT FACTORS	BEHAVIOR	PREDATORS AND COMPETITORS	SELECTED REFERENCES
Eggs	Eggs released off-shore in two distinct waves; spring spawning occurs in the Gulf Stream; summer spawning occurs over the continental shelf.	Not applicable	No information	Not applicable	No information	Lippson et al. 1979 Hildebrand and Schroeder 1928 Jones et al. 1978 Daiber et al. 1976
Larvae	No information	No information	No information	No information	No information	
Juvenile	0-37.5 ppt salinity. The larger the juvenile population, the greater the penetration into the Bay.	- copepods - molluscs - planktivorous crustaceans - any fish smaller than themselves	Juveniles grow quickly during the first summer.	Juveniles from spring spawning enter the Bay in early summer; leave the Bay by late fall, heading offshore and southward.	No information	
Adult	7-34 ppt salinity. Both sexually mature and immature adults enter the Bay; the larger the adult population, the greater the penetration into the Bay.	Voracious predator - menhaden - silversides - bay anchovy - herring spp. - crustaceans - annelids	Bluefish are sexually mature at about 30.0 cm and reach a maximum length of 93.4 cm.	Bluefish, a marine species, enters the Bay in spring and summer to feed. Schools of bluefish move seasonally in relation to food abundance.	Compete with other top predators such as striped bass. Target of a commercial and recreational fishery.	

TABLE 2a. ENVIRONMENTAL CONDITIONS FOR SPAWNING AND DEVELOPMENT OF SELECT SPECIES

SPECIES	TEMPERATURE (°C) AND SALINITY CONDITIONS	SPAWNING AREAS	SPAWNING SEASON	ENVIRONMENTAL CONSTRAINTS	EGG CHARACTERISTICS AND HATCHING PERIOD
Alosa pseudoharengus Alewife	Water temperature: minimum 10.5; peak 18; maximum 29-31. Salinity: Freshwater to salinities less than 0.5 ppt.	Large rivers, small streams and ponds over detritus-covered bottom with vegetation; sometimes at depths about 3 m. Usually ascend streams further than blueback herring.	Late March through April in Maryland with spawning lasting only a few days for each spawning group.	Usually spawn in sluggish water 15-30 cm deep. The greatest spawning activity occurs at night.	Eggs are broadcast at random; demersal, semi-demersal, or pelagic; eggs lose adhesive property after several hours. 15 days at 7.2°C, 2.1 days at 29°C, 7 days at 15°C.
Alosa sapidissima American Shad	Water temperature: minimum 8; peak 17; maximum 26. (Spawning generally occurs at 12°-21°C). Salinity: Tidal-freshwater to 0.5 ppt.	Primarily in tidal-fresh water of rivers with areas of extensive flats; also over sand or pebbly bottom; often near mouths of creeks.	April - May Mid-May and July	Currents less than 0.3 or greater than 0.9 m sec^{-1}; depths of 0.9-12.2 m; eggs absent at less than 5 ppm oxygen.	Demersal or throughout water column. 17 days at about 12°C. 2 days at about 27°C.
Alosa aestivalis Blueback Herring	Water temperature: minimum 14; peak 21-26; maximum 27. Salinity: Fresh to brackish waters.	Fresh and brackish rivers and tributaries, never far above tidewater; over bottoms of clean swept sand and gravel to boulders.	April - May	Areas of relatively wide and deep ingress with swift flow.	Essentially pelagic, but demersal in still water. 80-94 hrs at 20-21°C. 55-58 hrs at 22.2-23.7°C.

TABLE 25. ENVIRONMENTAL CONDITIONS FOR SPAWNING AND DEVELOPMENT OF SELECT SPECIES

SPECIES	TEMPERATURE (°C) AND SALINITY CONDITIONS	SPAWNING AREAS	SPAWNING SEASON	ENVIRONMENTAL CONSTRAINTS	EGG CHARACTERISTICS AND HATCHING PERIOD
Brevoortia tyrannus Atlantic Menhaden	Water temperature: minimum 4.4; peak 15-18; maximum 23.6. Salinity: Minimum of 10 ppt. Usually greater than 25 ppt.	At sea, as far as 64 km offshore from mouth of Chesapeake Bay.	Fall and spring peaks.	No information	Buoyant, spherical eggs 42-54 hrs at 15-20°C
Ictalurus catus White Catfish	Water temperature: peak about 21. Salinity: Freshwater.	Still or running water; nests usually built near sand or gravel banks.	Late May to early June (Pennsylvania).	No information	Demersal, deposited in masses, guarded and aerated chiefly by male 6-7 days at 23.9-29.4°C
Ictalurus nebulosus Brown Bullhead	Water temperature: peak 21-25. Salinity: Freshwater.	Sluggish, weedy, muddy streams and lakes; nests occur in shelter of logs, rocks, or vegetation.	Late spring in Maryland; early April to August throughout the range.	Spawning occurs in early morning to early afternoon. Eggs exposed to sunlight have poor hatching success.	Adhesive, deposited in clusters; 50-10,000 eggs per nest, parents attend eggs. 5 days at 25°C 8 days at 20-21°C
Ictalurus punctatus Channel Catfish	Water temperature: minimum 21; peak 27; maximum 29. Salinity: Freshwater to 2 ppt.	Nests occur in weedy areas near lake shores, in protected sites, small streams, sometimes in very swift water.	March through July, possibly September; sometimes have two spawning peaks per season.	Growth reduction at less than 3.5 ppm dissolved oxygen.	Demersal, adhesive; deposited in large gelatinous masses of 2,500-20,000 eggs 5-10 days at 15.6-27.8°C 7-10 days at 24-26°C 6-9 days at 27-28°C

TABLE 2c. ENVIRONMENTAL CONDITIONS FOR SPAWNING AND DEVELOPMENT OF SELECT SPECIES

SPECIES	TEMPERATURE (^oC) AND SALINITY CONDITIONS	SPAWNING AREAS	SPAWNING SEASON	ENVIRONMENTAL CONSTRAINTS	EGG CHARACTERISTICS AND HATCHING PERIOD
Cynoscion regalis Weakfish	Water temperature: minimum 12; peak 18-24; maximum 32. Salinity: 12-32.5 ppt.	Large estuaries in deeper waters or inlets, sheltered coves and river mouths; some spawning may occur offshore but near mouths of estuaries.	May-August Spawn in cohorts, moving up bays until encountering low salinities, turning back and moving seaward; spawn near mouths of large estuaries.	Dissolved Oxygen: 4.3 ppm reduces hatching; 2.4 ppm prevents hatching. Changes in magnitude of 6^oC and 5-6 ppt may reduce egg survival.	Initially buoyant, becoming heavier with development. Hatch in about 1,000 degree hours within range of 12-31.5 ppt salinity.
Morone americana White Perch	Water temperature: minimum 7.2-10; peak 11-16; maximum about 20. Salinity: Freshwater to 4 ppt.	Fresh, tidal fresh, or slightly brackish water in rivers, tributary streams, and shallow coves.	Late March to early June; eggs are not released all at once, and ovulation may continue for 10 to 21 days.	A sudden drop in temperature of 2.2 to 2.8^oC may kill eggs.	Demersal, typically attached to rocks, debris, or vegetation. 24-144 hrs.
Morone saxatilis Striped Bass	Water temperature: minimum 11; peak 14-19; maximum 23. Salinity: Freshwater to salinity less than 3 ppt.	Large rivers and the upper portion of the Bay; spawning is concentrated within the first river kilometer above salt water.	Spawning occurs from the beginning of April through mid-June.	A minimum current of 30 cm sec^{-1} is needed to keep eggs in suspension; optimal currents are 1-2 m sec^{-1}. Maximum survival of eggs before water hardening occurs at about 1 ppt salinity.	Pelagic eggs, deposited near surface. 29-80 hrs. $I = 4.60T(^oC) + 131.6$ (I = Incubation time in hours).

TABLE 2d. ENVIRONMENTAL CONDITIONS FOR SPAWNING AND DEVELOPMENT OF SELECT SPECIES

SPECIES	TEMPERATURE (°C) AND SALINITY CONDITIONS	SPAWNING AREAS	SPAWNING SEASON	ENVIRONMENTAL CONSTRAINTS	EGG CHARACTERISTICS AND HATCHING PERIOD
Perca flavescens Yellow Perch	Water temperature: minimum 5; peak 8.5-11; maximum 23. Salinity: Freshwater to 2.5 ppt.	Tidal or non-tidal portions of rivers near shore, over substrates of sand, rock, gravel, or rubble; typically at depths of 1.5 to 3 m.	Spawning occurs from the end of February to April, with peak activity in mid-March.	Significant growth reduction at 2.0 ppm dissolved oxygen.	Eggs are deposited in long, flat, demersal or semi-buoyant ribbons in vegetation, or on sand, gravel, or mud. 11 to 30 days. 6 days at 20°C.
Leiostomus xanthurus Spot	Water temperature: minimum 4.	Well offshore in moderately deep water.	Late fall and winter.	No information	No information
Micropogonias undulatus Atlantic Croaker	Water temperature: minimum 4.	Offshore, though there are some unconfirmed reports of spawning in the Bay.	From August through December, peak activity in August and September. In Virginia, spawning may occur nearly the entire year, with spring and fall peaks.	No information	No information
Pomatomus saltatrix Bluefish	Water temperature: peak 18-26. Salinity: 25-35 ppt.	Primarily over the outer half of the continental shelf; maximum distance of 160 km from shore. Eggs have been reported in the extreme southern portion of the Bay.	From June through August, possibly beginning in May.	Peak spawning occurs near sundown (1900-2100 hrs.).	Found at surface. 44-46 hrs. at 18.5-22.2°C (x 20.3°C) 46-48 hrs. at 18.0-22.2°C (x 20.0°C)

TABLE 2e. ENVIRONMENTAL CONDITIONS FOR SPAWNING AND DEVELOPMENT OF SELECT SPECIES

SPECIES	TEMPERATURE (^oC) AND SALINITY CONDITIONS	SPAWNING AREAS	SPAWNING SEASON	ENVIRONMENTAL CONSTRAINTS	EGG CHARACTERISTICS AND HATCHING PERIOD
Callinectes sapidus Blue Crab	Water temperature: 19-29 for successful hatching. Salinity: Optimum hatch at salinities of 23-30 ppt when temperatures range from 21.6°-22.8°C. Eggs fail to hatch at salinities below 9 or above 32.9 ppt.	After mating, females migrate to the lower portion of the Bay where salinities are higher.	Mating occurs from June through October, and peaks in July and August. Eggs may be laid in late summer, or the sperm stored and used the following year.	Salinity and temperature influence the timing of spawning. Hatching apparently coincides with nighttime ebb tides.	Females produce 0.5-2.0 million eggs. The fertilized eggs are clustered in a mass and attached to the female's abdomen. The female broods the egg mass until hatching occurs, from 10 to 15 days.
Crassostrea virginica American Oyster	Water temperature: Spawning occurs when temperatures exceed 15°C in in New England, 18-19°C in Chesapeake Bay. Salinity: Optimum salinity range for egg development depends on salinity levels experienced during gametogenesis. For example, at adult acclimation salinities of 26.0-27.9 ppt, zygotes tolerate 12.5-35.0 ppt, with optimum salinities of 22.5 ppt.	Eggs and sperm are released into open waters around the oyster bar.	Spawning occurs during the warmer months; mid-July to to August is usually the peak spawning period. Females are stimulated to release eggs by the presence of viable sperm.	pH: Spawning does not occur below a pH of 6.0 or above 10. Normal embryonic development occurs at pH levels of 6.75-8.75; abnormal development occurs at pH of 9.0-9.5. Suspended sediment: Eggs are sensitive to silt levels; 0.59 g L^{-1}- 69% mortality, 1.0 g L^{-1}- 100% mortality.	Pelagic eggs are fertilized externally. Hatching occurs in 24 to 48 hours.

TABLE 21. ENVIRONMENTAL CONDITIONS FOR SPAWNING AND DEVELOPMENT OF SELECT SPECIES

SPECIES	TEMPERATURE (°C) AND SALINITY CONDITIONS	SPAWNING AREAS	SPAWNING SEASON	ENVIRONMENTAL CONSTRAINTS	EGG CHARACTERISTICS AND HATCHING PERIOD
Mercenaria mercenaria Hard Clam or Quahog	Water temperature: 22-24 Salinity: Egg stage; Tolerate 20-35 ppt Optimum 26.5-27.5 ppt.	Eggs and sperm are released into open waters.	Spawning occurs during neap tides.	Oxygen levels: Egg stage; normal development occurs at levels of 0.5 mg L^{-1}, while 100% mortality occurs at levels of 0.2 mg L^{-1}.	Pelagic eggs are fertilized externally.
Mya arenaria Soft-shell Clam	Water temperature: 10-20 triggers spawning activity; Optimum 14-15; Eggs are released in fall when temperatures reach 15.	Eggs and sperm are released into open waters.	Spawning occurs twice a year, in May-June and again in September and and October. Spawning occurs only at night.	The degree of maturation during spring can vary, depending upon the number of days the water temperature is correct for gamete formation.	Pelagic eggs are fertilized externally.

TABLE 3. ECOLOGY OF WETLANDS FOUND IN THE CHESAPEAKE BAY AREA

Major Wetland Categories	Wetland Types Within Each Category	Associated Plants	Percent of Total Bay Wetlands	Salinity (ppt) Tolerance	Habitat Conditions	Ecological Importance	Selected References
Coastal Saline	Salt meadows, irregularly flooded salt marshes, and regularly flooded salt marshes.	*Spartina patens*, *S. alterniflora*, *Baccharis halimifolia*, *Distichlis spicata*, *Iva frutescens*, *Juncus roemerianus*, *Scirpus* app.	33%	5-34	All wetlands have soil that is, at least periodically, saturated with water.	Wetlands act as filtering basins, collecting sediments. Wetlands buffer the forces of wave action, slowing shoreline erosion. Wetlands are a source of nutrients, contributing to primary production. Wetlands provide habitat for finfish, shellfish, birds, and mammals. Tidal marsh productivity equals or exceeds the productivity of agricultural land.	U.S. Army Corps. Eng. 1973 Lippson et al. 1979 Gosselink 1980 Horwitz 1978
Coastal Fresh	Coastal shallow fresh marsh, and coastal deep fresh marsh.	*Spartina cynosuroides*, *Scirpus* spp., *Typha* spp., *Pontederia cordata*, *Nuphar advena*	36%	0-5			
Inland Fresh	Seasonally flooded basins and flats, inland fresh meadows, inland shallow fresh marsh, shrub swamp, and wooded swamp.	*Nymphaea odorata*, *Pontederia cordata*, *Zizania aquatica*, *Salix* spp., *Taxodium distichum*, *Liquidambar styraciflua*, *Acer rubrum*	31%	Non-tidal freshwater			

TABLE 4a. ECOLOGY OF SUBMERGED AQUATIC VEGETATION FOUND IN CHESAPEAKE BAY

SPECIES	PRESENT LOCATION	TYPE OF REPRODUCTION	SALINITY+, TEMPERATURE TOLERANCE/OPTIMUM RANGE*	GROWTH FACTORS	DISEASES AND PARASITES	SELECTED REFERENCES
Ceratophyllum demersum Coontail	Fresh to slightly brackish areas, primarily in Virginia.	Vegetative reproduction; produces seeds during warm periods.	Salinity: 0-7 ppt. 0-5 ppt. Temperature: 20-35°C 20-35°C	Dormant Period: Winter Season of Maximum Biomass: late spring, summer Reproductive Season: during high summer temperatures	No data	Orth et al. 1979 Anderson and Macomber 1980 Stevenson and Confer 1978
Elodea canadensis Common waterweed	Sporadic in low-salinity areas throughout the Bay.	Fragmentation and formation of propagules.	Salinity: 0-10 ppt. 0-10 ppt. Temperature: No data	Dormant Period: No data Season of Maximum Biomass: No data Reproductive Season: No data	No data	Orth et al. 1982 Yeo 1965 Orth 1976
Vallisneria americana Wild celery	Found throughout the Bay in fresh to brackish water.	Tubers, runners, and seed production.	Salinity: 0-7 ppt. 0-4 ppt. Temperature: 18-35°C 18-35°C	Dormant Period: Winter Season of Maximum Biomass: Summer Reproductive Season: Summer	Pathogenic fungus *Rhizoctonia solani*	

+ Salinities at which the species grow; some may tolerate higher salinities for a brief time.

* Below this temperature range, the species become dormant.

TABLE 4b. ECOLOGY OF SUBMERGED AQUATIC VEGETATION FOUND IN CHESAPEAKE BAY

SPECIES	PRESENT LOCATION	TYPE OF REPRODUCTION	SALINITY+, TEMPERATURE TOLERANCE/OPTIMUM RANGE*	GROWTH FACTORS	DISEASES AND PARASITES	SELECTED REFERENCES
Myriophyllum spicatum Eurasian watermilfoil	Occurs primarily in the upper Bay in fresh to mesohaline waters.	Budding, fragmentation, rhizome growth, and seed production.	Salinity: 0-14.5 ppt. 0-10 ppt. Temperature: 1.5-35°C 10-30 °C	Dormant Period: Winter Season of Maximum Biomass: Late summer Reproductive Season: Summer	Lake Venice disease Northeast disease	Orth et al. 1979 Anderson and Macomber 1980 Stevenson and Confer 1978
Potamogeton pectinatus Sago pondweed	Occurs in mid-salinity areas, primarily on the eastern shore.	Sub-terranean tubers, auxillary tubers, and seed production.	Salinity: 0-12.5 ppt. 0-10 ppt. Temperature: 15-35°C 15-35°C	Dormant Period: Winter Season of Maximum Biomass: Summer Reproductive Season: Summer	Pathogenic fungus *Rhizoctonia solani*	Orth and Moore 1981 Yeo 1965 Orth 1976
Potamogeton perfoliatus Redhead grass	Wide distribution in mesohaline areas, especially Eastern Bay and Choptank River.	Rhizome growth and seed production.	Salinity: 0-13 ppt. 0-10 ppt. Temperature: 15-35°C 15-30°C	Dormant Period: Winter Season of Maximum Biomass: Summer Reproductive Season: Summer	No data	

+ Salinities at which the species grow; some may tolerate higher salinities for a brief time.
* Below this temperature range, the species become dormant.

TABLE 4c. ECOLOGY OF SUBMERGED AQUATIC VEGETATION FOUND IN CHESAPEAKE BAY

SPECIES	PRESENT LOCATION	TYPE OF REPRODUCTION	SALINITY$^+$, TEMPERATURE TOLERANCE/OPTIMUM RANGE*	GROWTH FACTORS	DISEASES AND PARASITES	SELECTED REFERENCES
Zannichellia palustris Horned Pondweed	Found in the mid-Bay region and brackish water sections of the tributaries.	Seed production	Salinity: 0-15 ppt. 0-15 ppt. Temperature: 10-30°C 15-25°C	Dormant Period: Late summer and winter. Season of Maximum Biomass: Spring and early summer. Reproductive Season: Spring	No data	Orth et al. 1979 Anderson and Macomber 1980 Stevenson and Confer 1978
Ruppia maritima Widgeongrass	Broadest range of any species, distributed from Eastern Neck south to the Bay mouth.	Rhizome growth and seed production.	Salinity: 5-34 ppt. 5-34 ppt. Temperature: 15-35°C 20-26°C	Dormant Period: Winter Season of Maximum Biomass: Early summer Reproductive Season: Summer	Pathogenic fungus Rhizoctonia solani	Orth and Moore 1981 Yeo 1965 Orth 1976
Zostera marina Eelgrass	Occurs primarily in Virginia where it is the dominant species.	Rhizome growth and seed production.	Salinity: 8-34 ppt. 10-34 ppt. Temperature: 0-29°C 8-20°C	Dormant Period: Late summer Season of Maximum Biomass: Spring, early summer Reproductive Season: Spring	Eelgrass wasting disease	

+ Salinities at which the species grow; some may tolerate higher salinities for a brief time.

* Below this temperature range, the species become dormant.

SECTION 2
ANALYSIS OF OYSTER HABITAT

MARYLAND DATA COLLECTION

Maryland oyster bars are natural, ranging in size from one to 4,850 acres with a mean size of 324 acres. Most of these bars were designated by the Maryland Oyster Survey (Yates 1913) at the conclusion of a six-year survey of the bottoms. The actual productivity of these bars has not yet been documented; however, it is known that proper substrate does exist in most of these areas. Since 1913, a limited number of bars were added by court order to deter private leasing; these bottoms were not surveyed.

Using the data from Yates' (1913) report and through personal communication, Merritt (1977) constructed oyster bar charts. Merritt's charts, the most recent and comprehensive, were used to identify, locate, and estimate unavailable bar acreages. The acreage values for most of Merritt's bars were taken from the natural oyster bar charts prepared in 1961 by the Coast and Geodetic Survey for the Maryland Department of Tidewater Fisheries, which were also based on Yates' 1913 survey. Other bar acreages were obtained from updated charts of natural oyster bars and a computer printout from the Maryland Department of Natural Resources Hydrographic Division. Some of the bar acreages were obtained from the new Maryland Bay Bottom Survey (1980 to 1982). Merritt's bars (1977) with unavailable acreages were estimated from his charts. Acreages of oyster habitat are shown by fisheries basin (Table 5) and CBP segment (Table 6).

Where CBP segment boundaries cut across bars, a planimeter was used to determine areas within each segment. All bars with available coordinates in Yates' (1913) survey were plotted on a CBP segmentation chart (Figure 1).

VIRGINIA DATA COLLECTION

The Virginia public oyster grounds only delineate the boundaries of naturally productive oyster beds (Haven et al. 1981). These areas are referred to as Baylor bottoms after James E. Baylor, who designated the areas in 1894. Baylor's survey did not include an examination of the bottom, nor was any biological data considered (Haven et al. 1981). Since 1894, 32,274 acres have been added by petition or by legislative action (Haven et al. 1981). The Baylor bottoms cover most of Virginia's estuaries (Figure 1).

Haven et al. (1981) surveyed these areas to determine the productivity and potential productivity based on substrate and depth. Bottoms comprised of oyster rocks, shell-mud or shell-sand at depths less than 7.6 m were classed as productive or potentially productive (for oysters). They are similar to the public bars in Maryland in that they both delineate areas where salinity, depth, and substrate are adequate for oyster production. The Baylor bottom acreages, productive or potentially productive acreages, and coordinates for Baylor bottoms were obtained from Haven et al. (1981) (see Table 7). Excluding the seaside eastern shore, all Baylor grounds were plotted on a CBP segmentation chart. Areas divided by a segment line were planimetered. The productive and potentially productive areas were represented by symbols on Haven's (1981) charts (1:20,000), which were also planimetered where divided by a segmentation line.

TABLE 5. ACRES OF PUBLIC AND LEASED OYSTER GROUNDS

	Basin	Public Oyster Grounds	Leased Grounds	Total
+	Chesapeake Bay North	0	21	21
+	Chesapeake Bay Upper Central	19,038	0	19,038
+	Chester River	5,547	0	5,547
+	Eastern Bay	26,979	212	27,191
+	Choptank River	1,378	454	1,832
+	Chesapeake Bay Lower Central	29,173	778	29,951
	Patuxent River	7,543	1,119	8,662
	Honga River	15,475	1	15,476
	Fishing Bay	11,811	333	12,144
	Nanticoke River	577	190	767
	Wicomico River	568	1,268	1,836
	Chesapeake Bay South	32,315	0	32,315
	Tangier Sound	31,043	889	31,932
	Pocomoke Sound	4,899	4,303	9,202
	Potomac River	28,523	9,389	37,912
	Rappahannock River	44,254	19,022	63,276
	Piankatank River	16,000	328	16,328
	Chesapeake Bay General	35,566	20,170	55,736
	Mobjack Bay	17,061	1,516	18,577
	York River	2,381	26,729	29,110
	Mattaponi River	0	0	0
	Pamunkey River	0	0	0
	Chicahominy River	0	0	0
	James River	25,152	13,260	38,412
	TOTAL	355,283	99,982	455,265

+ These acreages were taken from the new Maryland Bay Bottom Survey (1980 to 1982).

TABLE 6. ACREAGE OF OYSTER BARS IN MARYLAND BY CBP SEGMENT

Segment	Oyster Bar Acreage	Segment	Oyster Bar Acreage
CB-1			
CB-2	46	LE-3	
CB-3	26676	RET-3	
CB-4	50695	TF-3	
CB-5	32315		
CB-6		ET-1	
CB-7		ET-2	
CB-8		ET-3	
		ET-4	7948
WT-1		EE-1	22653
WT-2		EE-2	29329
WT-3		EE-3	94151
WT-4	947	ET-5	10314
WT-5		ET-6	577
WT-6	226	ET-7	568
WT-7	1049		
WT-8	1465		
LE-1	7322		
RET-1	214		
TF-1	7		
LE-2	25355		
RET-2	400		
TF-2			

TABLE 7. BAYLOR GROUNDS AND PRODUCTIVE AND POTENTIALLY PRODUCTIVE BAYLOR GROUND ACERAGES IN VIRGINA

Segment	Virginia Public Oyster Ground (Baylor's)	Productive & Potentially Productive Baylor Grounds Baylor Bottoms Acreage	Percent Productive or Potentially Productive Baylor's Acreage
CB-1			
CB-2			
CB-3			
CB-4			
CB-5	14477.4	521.2	3.6
CB-6	17714.6	609.8	3.4
CB-7	3374.3	560.1	16.6
WT-1			
WT-2			
WT-3			
WT-4			
WT-5			
WT-6			
WT-7			
WT-8			
LE-1			
RET-1			
TF-1			
LE-2	2767.7	817.4	29.5
RET-2			
TF-2			
LE-3	46878.0	9476.2	20.2
RET-3	4666.7	2004.1	42.9
ET-1			
ET-2			
ET-3			
ET-4			
EE-1			
EE-2			
ET-5			
EE-3	28118.4	5397.8	19.2
WE-4	17061.1	1439.4	8.4
LE-4	2210.8	1048.6	47.4
RET-4	170.1	8.5	5.0
TF-4			
LE-5	25151.8	16245.6	64.6
RET-5			
TF-5			
ET-7			
ET-8			
ET-9			
ET-10			
Totals	162590.9	38.128.7	

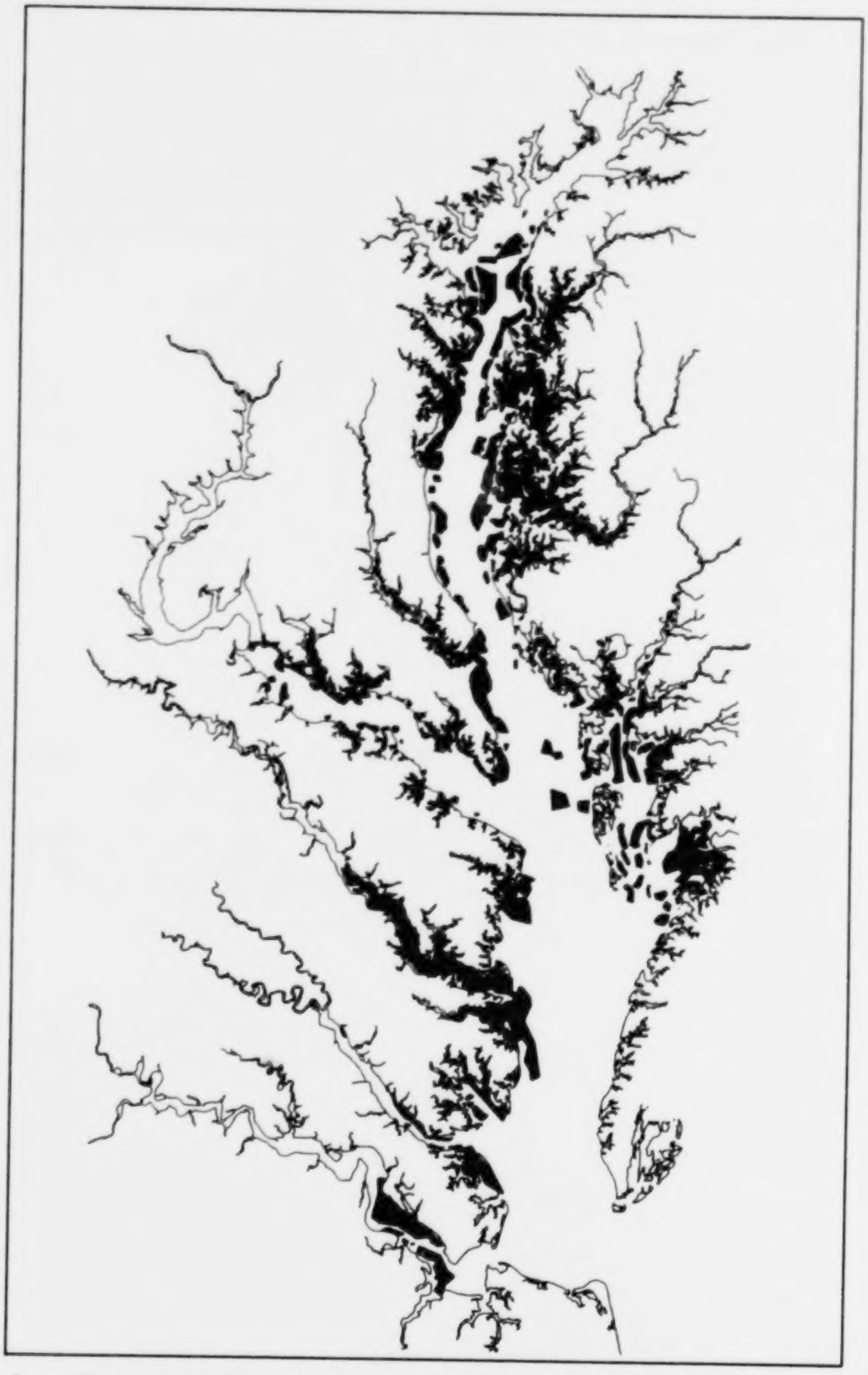

Figure 1. Chesapeake Bay, Maryland oyster bars (Yates 1913), and Virginia Baylor bottoms (Haven 35 al. 1981).

SECTION 3

SOURCES AND ANALYSIS OF FISHERIES LANDING DATA

DATA COLLECTION

Historical records of the fisheries were obtained from Power (1958) and statistical digests of the U.S. Fish and Wildlife Service and the National Marine Fisheries Service, Fishery Statistics of the United States. The single exception is that the Maryland Department of Natural Resources' catch records were used for all finfish in Maryland (except the Potomac) for the period 1962 to 1980 because these records were more complete.

The landings or harvest data used within this study to depict trends were obtained from the files of the National Marine Fisheries Service and Maryland's Department of Natural Resources. These landings were derived from reports submitted by commercial fishermen or from surveys taken of the fishermen and/or market houses. It should be recognized that these landings do not constitute a statistically precise sampling method, but they are the only data that have been collected over a long period of time that can be used to depict trends. The validity of the harvest data is further complicated by the changes in the collection method over the reported time period. The longest record going back to the late 1800's was originally collected by the U.S. Department of Commerce Bureau of Fisheries through a survey of market houses and from reports from the states that maintained a data collection system. These earlier reports collated the data as a state total (except for the Potomac River) instead of using a river system breakdown. The more recent data collection system, and that used for data within this report by river system (1962 to 1980 data), was started by the State of Maryland in 1944 and is still used to date. The data for Virginia for the 1962 to 1980 time period was collected by the National Marine Fisheries Service (NMFS) until 1976. Since that date, the Virginia Marine Resources Commission (VMRC) has gathered information.

The major difference between the Maryland and Virginia system for Chesapeake Bay landings is that Maryland data is collected from mandatory monthly reports from the individual fishermen; the Virginia data, formerly collected by NMFS and most recently by VMRC, is gathered through a volunteer survey report from the market houses. The exception to this system difference is for oysters. Both states require mandatory reporting by the oystermen because of the tax that is levied on oysters.

For individual river system reports within Chesapeake Bay, the Potomac River has historically been reported separately. Prior to 1963, the Potomac River landings were compiled by NMFS from their own data for the Virginia licensed fishermen and from Maryland State Department of Natural Resources for Maryland licensed fishermen. Since 1963, Potomac River landings have been compiled by the Potomac River Fisheries Commission from mandatory monthly reports submitted to them by both Virginia and Maryland licensed fisherman fishing the Potomac.

GEOGRAPHIC COMPARTMENTATION OF LANDINGS DATA

Our basic unit of analysis was the NOAA water code (Tables 8 and 9). These codes are grouped into basins (Tables 10 and 11). The basins are

TABLE 8. NOAA CODES -- VIRGINIA

0	Unknown (improper listing)
1	Chincoteague Bay (62-75) Back Bay (76-80)
3	Chesapeake Bay General plus Tribs. not numbered (62-75), Back River (76-80)
4	Great Wicomico River (62-75)
5	James River (62-75), Bogue Bay (76-80)
7	Chicahominy River (62-75), Bradford Bay (76-80)
8	Mobjack Bay (62-75)
9	York River (62-75), Burtons Bay (76-80)
11	Pamunkey River (62-75), Chesapeake Bay Gen. (76-80)
12	Piankatank River (62-75)
13	Mattaponi River (62-75), Chickahominy River (76-80)
15	Chincoteague Bay (76-80)
17	Coan River (76-80)
18	Cobb Bay (ocean)
19	Currioman Bay (77-80)
21	Corrotoman River (76-80)
23	Atlantic Ocean (62-75), East River (76-80)
24	Atlantic Ocean
25	Elizabeth River (1977)
26	Rappahannock River (62-75)
27	Fleets Bay (76-80)
28	Potomac River (62-75)
29	Potomac River Tribs. (62-75), Great Wicomico River (76-80)
30	Misc. Tribs of Chesapeake Bay (62-75)
31	Hog Island Bay (76-80)
33	Back Bay (62-75), Horn Harbor (76-80)
37	James River Gen. (76-78)
39	Lafayette River (1977)
41	Little Wicomico River (76-80)
43	Lower Machodoc Creek (76-80)
45	Lynnhaven Bay (76-80)
47	Magothy Bay (76-80)
49	Mattaponi River (76-80)
50	Mattox Creek
51	Metomkin Bay (76-80)
53	Milford Haven (76-80)
55	Mobjack Bay (76-80)
57	Nansemond River (76-80)
59	Nomini Bay (76-80)
61	North River (76-80)
62	Unknown (Possibly James River)
63	Outlet Bay (77-78)
67	Pamunkey River (76-80)
69	Piankatank River (76-80)
70	Pocomoke River (76-78)
72	Pocomoke Sound (76-80)

(continued)

TABLE 8. (Continued)

73	Poquoson River (76-80)
74	Potomac Creek
75	Potomac River gen. (76-80)
76	Potomac River tribs (unclassified) (76-80)
77	Rappahannock River gen. (76-80)
78	Rosier Creek (Potomac)
79	Severn River (76-80)
81	South Bay (76-77)
83	Swash Bay (1980)
85	Upper Machodoc Creek (76-79)
87	Ware River (76-80)
89	Warwick River (76-79)
91	Willoughby Bay (76-79)
92	Winter Harbor
93	Yeocomico River (76-80)
95	York River Gen. (76-80)
97	Unclassified Seaside Bays and Rivers (76-80)
99	Unclassified Tributaries of Chesapeake Bay (76-80)
111	Chesapeake Bay (Upper Western Section) (76-80)
117	Misprint (possibly 177 Rappahannock River)
137	James River (Lower Section) (76-80)
175	Potomac River (Lower Section) (76-80)
177	Rappahannock River (Lower Section) (76-80)
195	York River (Lower Section) (76-80)
211	Chesapeake Bay (Upper Eastern Section) (76-80)
237	James River (Central Section) (76-80)
275	Potomac River (Lower Central Secton) (76-80)
277	Rappahannock River (Central Section) (76-80)
295	York River (Central Section) (76-80)
311	Chesapeake Bay (Lower Western Section) (76-80)
337	James River (Upper Section) (76-80)
375	Potomac River (Upper Central Section) (1976)
377	Rappahannock River (Upper Section) (76-80)
395	York River (Upper Section) (76-80)
411	Chesapeake Bay (Lower Eastern Section) (76-80)
515	Atlantic Ocean
522	Atlantic Ocean
523	Atlantic Ocean
524	Atlantic Ocean
525	Atlantic Ocean
526	Atlantic Ocean
533	Atlantic Ocean
537	Atlantic Ocean
555	Atlantic Ocean
600	Atlantic Ocean
612	Atlantic Ocean
613	Atlantic Ocean

(continued)

TABLE 8. (Continued)

615	Atlantic Ocean
616	Atlantic Ocean
620	Atlantic Ocean
621	Atlantic Ocean
622	Atlantic Ocean
623	Atlantic Ocean
624	Atlantic Ocean
625	Atlantic Ocean
626	Atlantic Ocean
627	Atlantic Ocean
631	Atlantic Ocean
632	Atlantic Ocean
633	Atlantic Ocean
635	Atlantic Ocean
636	Atlantic Ocean
700	Atlantic Ocean

TABLE 9. NOAA CODES -- MARYLAND

000	Totals
001	Assawoman Bay
003	Back River
005	Big Annamessex River
006	Blackwater River
007	Bohemia River
009	Bush River
011	Chesapeake Bay General - totals
013	Chesapeake Bay - North of Sassafras River
020	Chesapeake Bay - South of Cove Point
023	Chesapeake Bay - North of Sassafras River
025	Chesapeake Bay - North of Bridge, South of Sassafras River
027	Chesapeake Bay - South of Bridge, North of Cove Point
029	Chesapeake Bay - South of Cove Point
031	Chester River
131	Chester River below Deep Point
231	Chester River above Deep Point
033	Chincoteague Bay
037	Choptank River
137	Choptank River Below Rt. 50 Bridge
237	Choptank River Above Rt. 50 Bridge
039	Eastern Bay
041	Elk River
043	Fishing Bay
045	Gunpowder River
046	Herring Bay
047	Honga River
048	Hoopers Strait
040	Isle of Wight Bay
049	Isle of Wight Bay
051	Little Annemessex River
053	Little Choptank River
055	Magothy River
057	Manokin River
059	Middle River
060	Miles River
062	Nanticoke River
162	Nanticoke River Below Long Point
262	Nanticoke River Above Long Point
064	Northeast River
066	Patapsco River
068	Patuxent River
168	Patuxent River Below Bridge at Benedict
268	Patuxent River Above Bridge at Benedict
06	Patuxent River
070	Pocomoke River
072	Pocomoke Sound

(continued)

TABLE 9. (Continued)

073	Potomac River
173	Potomac River from Bay to Colton Point
273	Potomac River Colton Point to Rt. 301 Bridge
373	Potomac River Rt. 301 Bridge to Quantico
473	Potomac River Quantico to Little Falls
074	Potomac River
174	Potomac River - Md. Tributaries to lower Potomac
274	Potomac River - Md. Tributaries to lower central Potomac
374	Potomac River - Md. Tributaries to upper central Potomac
474	Potomac River - Md. Tributaries to upper Potomac
076	St. Jerome Creek
078	St. Mary's River
080	Sassafras River
082	Severn River
084	Sinepuxent Bay
086	Smith Creek
088	South River
089	Susquehanna Flats
090	Susquehanna River
092	Tangier Sound
093	Transquaking River
094	West River
096	Wicomico River - Wicomico County
099	Wye River
012	Atlantic Ocean
098	Atlantic Ocean
375	Atlantic Ocean
525	Atlantic Ocean
537	Atlantic Ocean
613	Atlantic Ocean
614	Atlantic Ocean
615	Atlantic Ocean
616	Atlantic Ocean
621	Atlantic Ocean
622	Atlantic Ocean
625	Atlantic Ocean
626	Atlantic Ocean
627	Atlantic Ocean
631	Atlantic Ocean
632	Atlantic Ocean
9000	Pacific Ocean

TABLE 10. VIRGINIA NOAA CODES GROUPED BY BASIN

Basin	Year	NOAA Code
Chincoteague Bay	1962-1975	1
	1976-1980	15
James River	1962-1975	5
	1976-1980	37
		137
		237
		337
		25
		39
		57
		89
		91
Great Wicomico	1962-1975	4
	1976-1980	29
Chicahominy	1962-1975	7
	1976-1980	13
Mobjack Bay	1962-1975	8
	1976-1980	55
York River	1962-1975	9
	1976-1980	95
		195
		295
		395
		87
		3
		23
		61
		73
		79
Pamunkey River	1962-1975	11
	1976-1980	67
Piankatank River	1962-1975	12
	1976-1980	69
Mattaponi River	1962-1975	13
	1976-1980	49
Rappahannock River	1962-1975	26
	1976-1980	21
		77
		177
		277
		377
Potomac River	1962-1975	28
	1976-1980	75
		175
		275
		375

(continued)

TABLE 10. (Continued)

Basin	Year	NOAA Code
Potomac River Tributaries	1962-1975	29
	1976-1980	50
		74
		76
		17
		19
		43
		59
		78
		85
		93
Back Bay	1962-1975	33
	1976-1980	1
	1962-1975	23
	1976-1980	5
		7
		9
		18
		24
		31
		47
		51
		63
		81
		83
		97
		515
Misc. Tributaries of Chesapeake Bay	1962-1975	30
	1976-1980	99
		41
		45
		53
Chesapeake Bay Gen.	1962-1975	3
	1976-1980	111
		211
		311
		411
		11
		27

TABLE 11. MARYLAND NOAA CODES GROUPED BY BASIN

Chester River (004)
031
131
231

Choptank River (008)
37
137
237

Eastern Bay (010)
039
060
099

Fishing Bay (012)
043
093
006

Chesapeake Bay North (014)
007
013
041
064
080
089
090
023

Chesapeake Bay - Upper Central (016)
003
009
025
045
055
059
066

Chesapeake Bay - Lower Central (018)
027
046
053
082
088
094

Chesapeake Bay South (020)
076
029
020

Honga River (030)
047
048

Nanticoke River (032)
062
162
262

Patuxent River (034)
68
69
168
268

Pocomoke River (036)
070

(continued)

TABLE 11. (Continued)

Pocomoke Sound (038)
072

Potomac River (040)
73
74
78
86
173
174
273
274
373
374
473
474

Ocean (042)*
1
12
23
33
40
49
84
98
375
525
537
613
614
615
616
621
622
625
626
627
631
632
9000 (Pacific Ocean)

Tangier Sound (046)
005
051
057
092

Wicomico River (048)
096

Totals
0
11

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* Note: Ocean codes omitted from Chesapeake Bay landings analysis.

shown in Figure 2. In some cases, NOAA codes were aggregated into regions (Table 12). These regions can be related to Chesapeake Bay segments but, in most cases, the relationship is not exact. Use of NOAA water codes was complicated by the fact that application of the codes by NOAA was changed during the period of record. NOAA went through a change in its coding system for the Virginia data in 1975. Virginia data from 1962 to 1975 is contained within the old coding system that lumped an entire river basin. The new coding system divides rivers into more than one unit. The 1976 to 1980 landings are reported under this new coding system. To have consistent 1962 to 1980 landings, it was necessary to go back to the old codes by combining the new ones to match the old system. For example, under the old method, the Rappahannock River was considered as one basin; under the new method, the Rappahannock is divided into four units. In addition, the codes do not remain consistent from year to year for the same area; i.e., code 1 from 1962 to 1975 represents landings for Chincoteague Bay, but the same code for 1976 to 1980 shows landings from Back Bay (see Table 8). The situation with Maryland data is not the same because data has been reported under the new system since 1962. However, because we wanted the Maryland data to be consistent with the Virginia data, we used the old system for reporting Maryland data as well.

Chapter 2 reports fisheries landings in pounds per acre by basin. Each of these basins was planimetered from CBP computer generated maps. Table 13 shows the acreages of each basin and the percentage of that basin when compared to three larger areas: western shore, main Bay, and eastern shore.

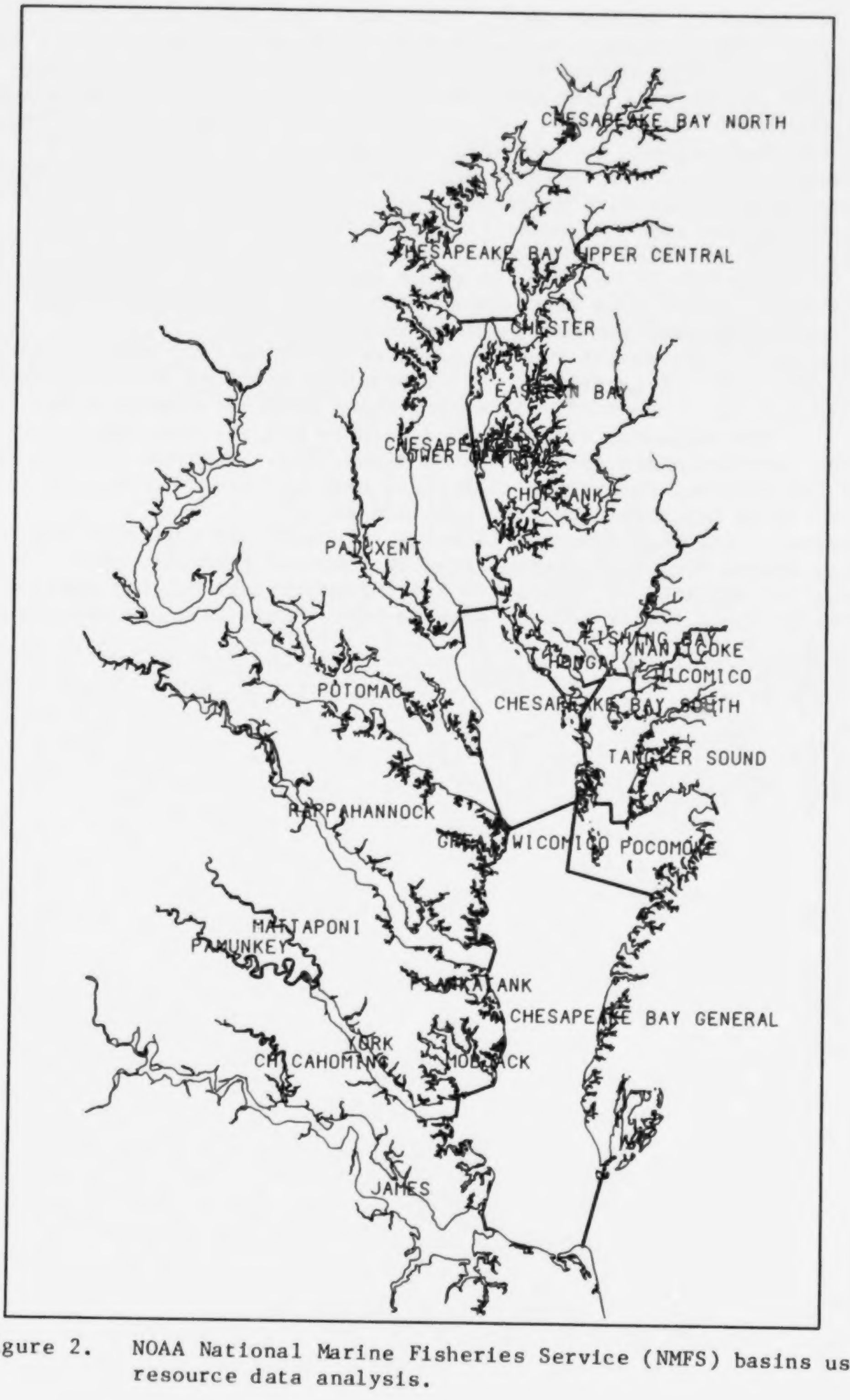
CHESAPEAKE BAY NORTH
CHESAPEAKE BAY UPPER CENTRAL
CHESTER
EASTERN BAY
CHESAPEAKE BAY LOWER CENTRAL
CHOPTANK
PATUXENT
FISHING BAY
HONGA
NANTICOKE
WICOMICO
CHESAPEAKE BAY SOUTH
POTOMAC
TANGIER SOUND
RAPPAHANNOCK
GREAT WICOMICO
POCOMOKE
MATTAPONI
PAMUNKEY
PIANKATANK
CHESAPEAKE BAY GENERAL
YORK
CHICAHOMINY
MOBJACK
JAMES

Figure 2. NOAA National Marine Fisheries Service (NMFS) basins used in resource data analysis.

TABLE 12. AGGREGATION OF NOAA WATER CODES INTO REGIONS AND ASSOCIATED CHESAPEAKE BAY PROGRAM SEGMENTS

Region	Segments	NOAA Codes
Upper Bay	CB-1	M090
		M089
	CB-2	M013
		M023
	CB-3	M025
Upper Eastern Shore	ET-1	M064
	ET-2	M041
		M007
	ET-3	M080
	ET-4	M031
		M231
		M131
Western Tributaries	WT-1	M009
	WT-2	M045
	WT-3	M059
	WT-4	M003
	WT-5	M066
	WT-6	M055
	WT-7	M082
	WT-8	M088
		M094
Mid-Eastern Shore	EE-1	M039
		M099
		M060
	EE-2	M137
		M053
	ET-5	M037
		M237
Patuxent M069	TF-2	M268
M068		
	RET-1 & LE-1	M168
Potomac	TF-2	M473
		M474
		V475
V28 (62-75)	RET-2	M373
V75 (76-80)		M374
		V375
	LE-2	M273
		M274
		V275
		M173
		M174
		V175
		M073
		M074

(continued)

TABLE 12. (Continued)

Region		Segments	NOAA Codes
			M078
			M086
			V029 (62-75)
			V076 (76-80)
			V050
			V074
			V017
			V019
			V043
			V059
			V085
			V078
			V093
			V004 (62-75)
			V029 (76-80)
			V076 (76-80)
			V041
Lower Eastern Shore		ET-6	M062
			M162
			M262
		ET-7	M096
		ET-8	M057
		ET-9	M005
		ET-10	M070
			M072
		EE-3	M006
			M093
			M043
			M047
			M048
			M092
			M051
Mid-Bay		CB-4	M027
			M046
		CB-5	M076
			V027 (76-80)
			M020
Rappahannock	V077 (76-80)	TF-3	V377 (part)
	V026 (62-75)	RET-3	V377 (part)
			V277 (part)
		LE-3	V277 (part)
			V021
			V177
			V012 (62-75)
			V069

(continued)

TABLE 12. (Continued)

Region		Segments	NOAA Codes
York		TF-4	V013 (62-75)
			V049
			V011 (62-75)
			V067
	V009 (62-75)	RET-4	V395
	V095 (76-80)		
		LE-4	V295
			V195
		WE-4	V008 (62-75)
			V003 (76-80)
			V073
			V055
			V079
			V087
			V061
			V023
James		TF-5	V337 (part)
	V005 (62-75)	RET-5	V337 (part)
	V037 (76-80)		V007 (62-75)
			V013
		LE-5	V237
			V089
			V057
			V137
			V025
			V039
			V091
Lower Bay		CB-6	V053
			V033 (76-80)
			V311 (part)
	V003 (62-75)		
	V030 (62-75)	CB-7	V211
			V411
		CB-8	V311 (part)
			V045
			V111 (76-80)
			V099 (76-80)

TABLE 13. AREAS AND PERCENTAGES OF TOTALS OF FISHERIES BASINS[1]

Basin	Area (acres)	Percent of Western Shore
Patuxent River	34,019	5.5
Potomac River	299,167	48.6
Rappahannock River	85,185	13.8
York River	41,120	6.7
James River	156,307	25.4
Sub-total	615,798 (22.9 % of total)	100.0

Basin	Area (acres)	Percent of Main Bay
Chesapeake Bay		
North	73,594	4.7
Upper Central	185,302	11.8
Lower Central	269,838	17.2
South	259,199	16.5
General	777,833	49.7
Sub-total	1,565,766 (58.3 % of total)	100.0

Basin	Area (acres)	Percent of Eastern Shore
Chester River	39,041	7.7
Eastern Bay	60,396	12.0
Choptank River	82,407	16.4
Honga River	33,345	6.6
Fishing Bay	19,908	3.9
Nanticoke River	16,593	3.3
Wicomico River	8,210	1.6
Tangier Sound	83,315	16.5
Pocomoke Sound	160,444	31.8
Sub-total	503,659 (18.7 % of total)	100.0
Total Area	2,685,223	

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[1] One acre = 4048.58 m^2

SECTION 4
ANALYTICAL APPROACHES FOR DETERMINING TRENDS IN FISHERIES

Treatments of landings data include plotting of three-year moving averages, deviation from the mean, cumulative deviation from the mean, comparison of means by Student t and binomial probability tests, and correlation analysis. Trends were determined by inspection and verified by comparing pre- and post-1970 means for the period of record (1962 to 1980).

A number of caveats must be offered to those who might wish to use fisheries landings data (as they are presently collected) to identify cause and effect relationships. Among those considerations that complicate the definition of causal mechanisms and the ability to predict future variability in fisheries are: insufficient accuracy in measuring fish-stock abundance (landings data are not meant to measure abundance); and the complexity of natural processes acting on fishery success, including natural and economic factors (Doubleday 1980). The impact of these factors on the scientific ability to predict the dynamics of Chesapeake Bay fish stocks is elaborated upon in the following paragraphs.

MEASUREMENT

Even when using scientifically collected estimates of fish biomass by acoustic and trawl surveys, resulting indices of relative abundance typically have ± 50 percent margins of error unless more than 100 sets (samples) are made at any given locale (Doubleday 1980). Landings figures are not actual landings, or a statistically precise sampling of actual landings, but reflect reports and estimates made by individual fishermen. Such reports can easily be biased by poor individual record keeping and the fear of competition from other fishermen or tax avoidance. The Maryland Watermen's Association (1978, 1979) recently suggested that the Maryland commercial catch may be underestimated by as much as four to seven times when stocks are abundant and approximately equal when stocks are low. One final major complicating factor is that for some species that are also sought by sportfishermen, the sports landings may equal or exceed commercial landings. For example, it has been estimated that the sports catch of striped bass in Chesapeake Bay is equal to the commercial catch while the sport catch of bluefish is nearly 20 times the commercial catch (Williams et al. 1982).

McHugh (1981) states that "it is probably a conservative estimate that recreational fishermen took at least twice as much as commercial fishermen" in Delaware waters in the early 1970's. It can be safely assumed that recreational fisheries are growing in the U.S.

Finally Rothschild et al. (1981) and Bortone (1982) discuss the need to normalize fisheries landing statistics using catch per unit effort to more accurately predict actual stock abundance. Although both authors have attempted normalization procedures, Rothschild et al. (1981) state that the fishing effort statistics in their present form are "too crude for detailed analyses" and offer suggestions for improved catch per unit effort information.

COMPLEXITY

As discussed in Chapter 2 of this publication, climate and major natural events create a number of interacting and sometimes conflicting effects on the determination of year class size. Multiple hypotheses can be put forward to explain observed events; data are usually not complete enough to select "the" single cause, if one exists.

SECTION 5

SAV DECLINE AND GEOGRAPHIC ANALYSIS

Decline in SAV abundance has been documented by Orth et al. (1982), and is shown in Figures 3 through 7.

A 650-station survey has been conducted annually by the Maryland Department of Natural Resources and the U.S. Fish and Wildlife Service Migratory Bird and Habitat Research Laboratory. Sampling stations were distributed among CBP segments as shown in Table 14. Regression analyses of results, showing declines in percentage of sites vegetated and diversity, are shown in Tables 15 and 16.

ASSESSMENT OF PRESENT CONDITION IN CHESAPEAKE BAY SEGMENTS

Tables 17, 18, and 19 assess the present condition of SAV in Chesapeake Bay segments. Figure 8 displays the location of quad areas used for areal sampling of SAV; Figure 9 shows the percent of expected SAV occupied in 1978 for each sampling area. A discussion of this information is found in Chapter 2, Section 3.

TABLE 14. TOTAL SAV OBSERVATIONS FOR EACH SEGMENT, 1971 TO 1981. MARYLAND SAV ANNUAL SURVEY, MD DNR, AND U.S. FWS (MUNRO 1981)

Segment	Number of observations	Segment	Number of observations
CB-1	317	ET-7	110
CB-2	118	ET-8	120
CB-3	277	ET-9	129
CB-4	522	LE-1	311
CB-5	559	RET-1	99
EE-1	461	TF-1	87
EE-2	635	WT-1	50
EE-3	1386	WT-2	37
ET-1	72	WT-3	77
ET-2	152	WT-4	66
ET-3	110	WT-5	209
ET-4	304	WT-6	70
ET-5	194	WT-7	120
ET-6	165	WT-8	77

TOTAL number of observations 6,834

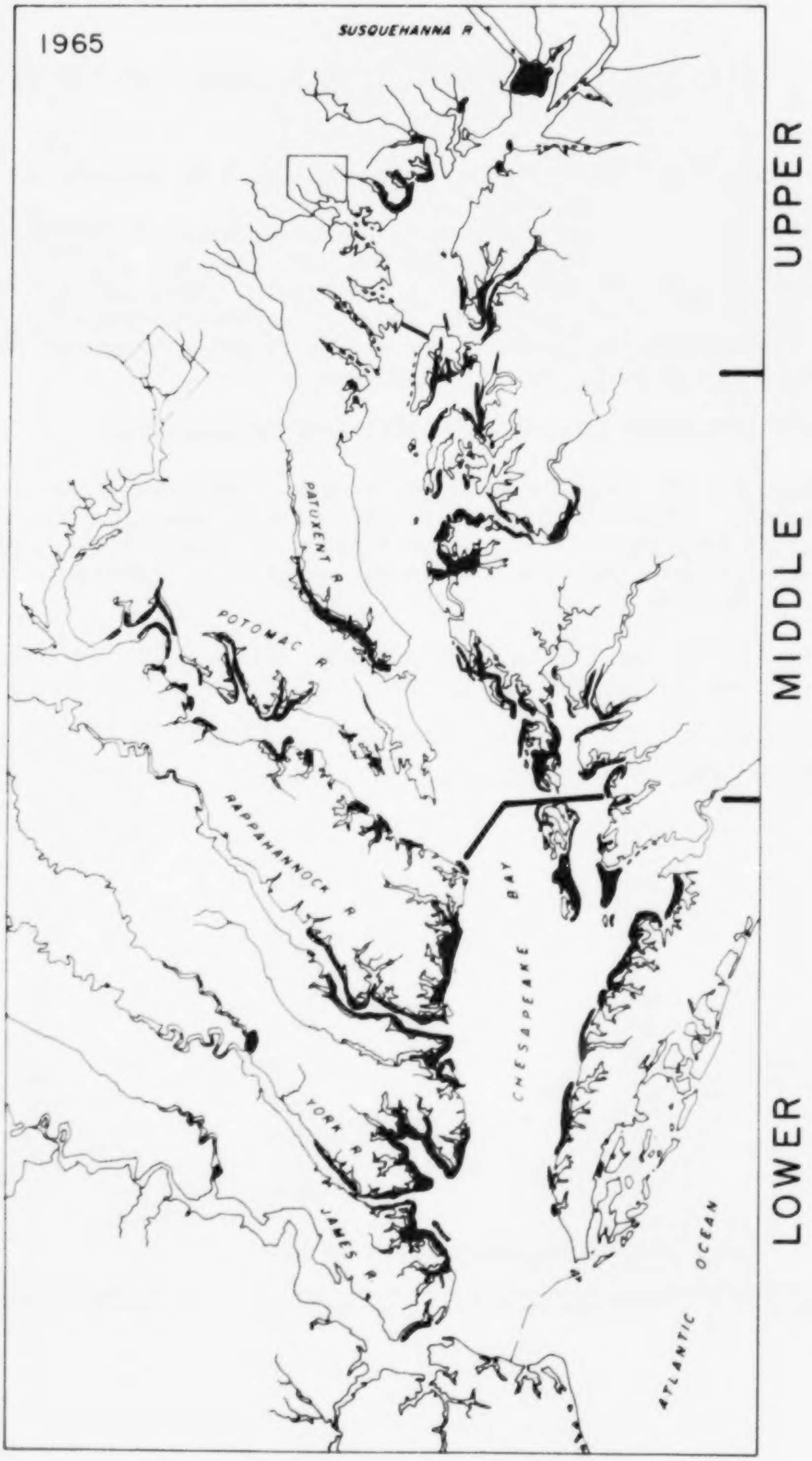
1965
SUSQUEHANNA R
UPPER
PATUXENT R
MIDDLE
POTOMAC R
RAPPAHANNOCK R
CHESAPEAKE BAY
YORK R
LOWER
JAMES R
ATLANTIC OCEAN

Figure 3. Distribution of submerged aquatic vegetation in Chesapeake Bay, 1965 (after Orth et al. 1982).

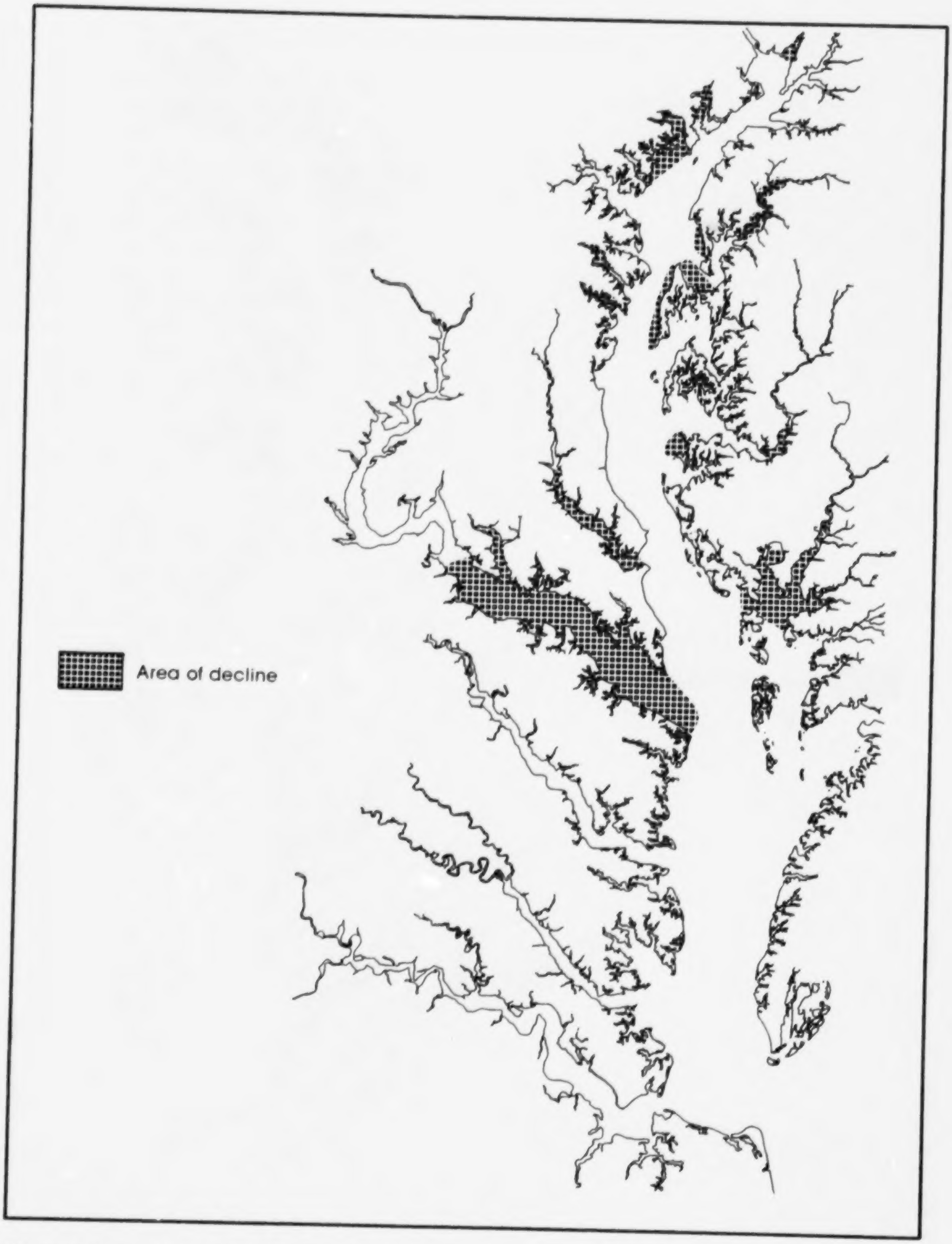

Figure 4. Area of submerged aquatic vegetation decline between 1965 and 1970 (after Orth et al. 1982). Loss of SAV during this period was concentrated in the upper and mid-Bay regions, particularly the Patuxent River, lower Potomac River, and the Wicomico, Nanticoke, and upper Choptank Rivers.

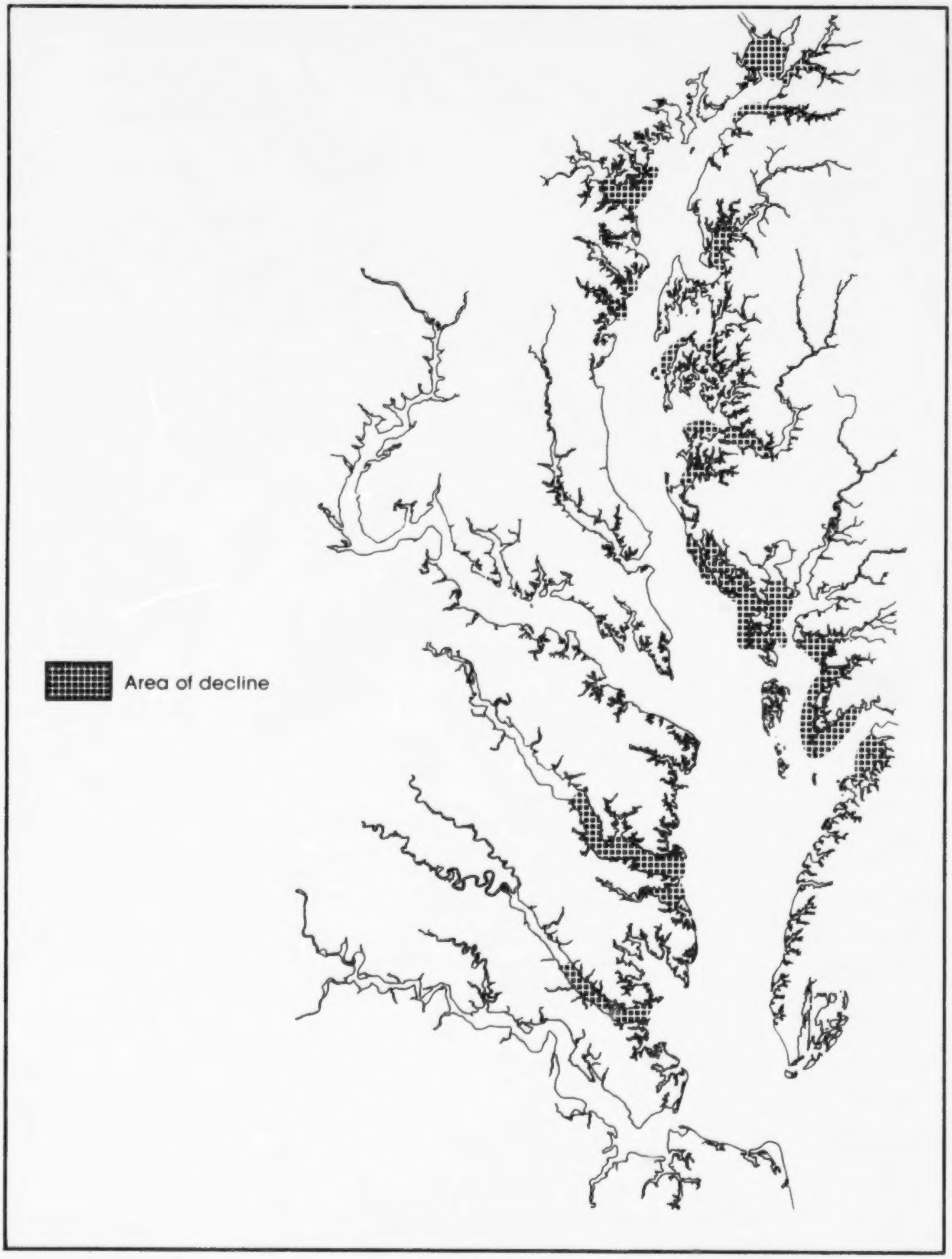

Figure 5. Area of submerged aquatic vegetation decline between 1970 and 1975 (after Orth et al. 1982). A major loss of remaining populations occurred during this period, largely because of runoff and sediment load acompanying Tropical Storm Agnes. Primarily affected were the Susquehanna Flats, lower reaches of the Elk, Sassafras, Back, Patapsco, Choptank, Rappahannock, Pocomoke, and York Rivers, and the Honga River and Bloodworth Island areas.

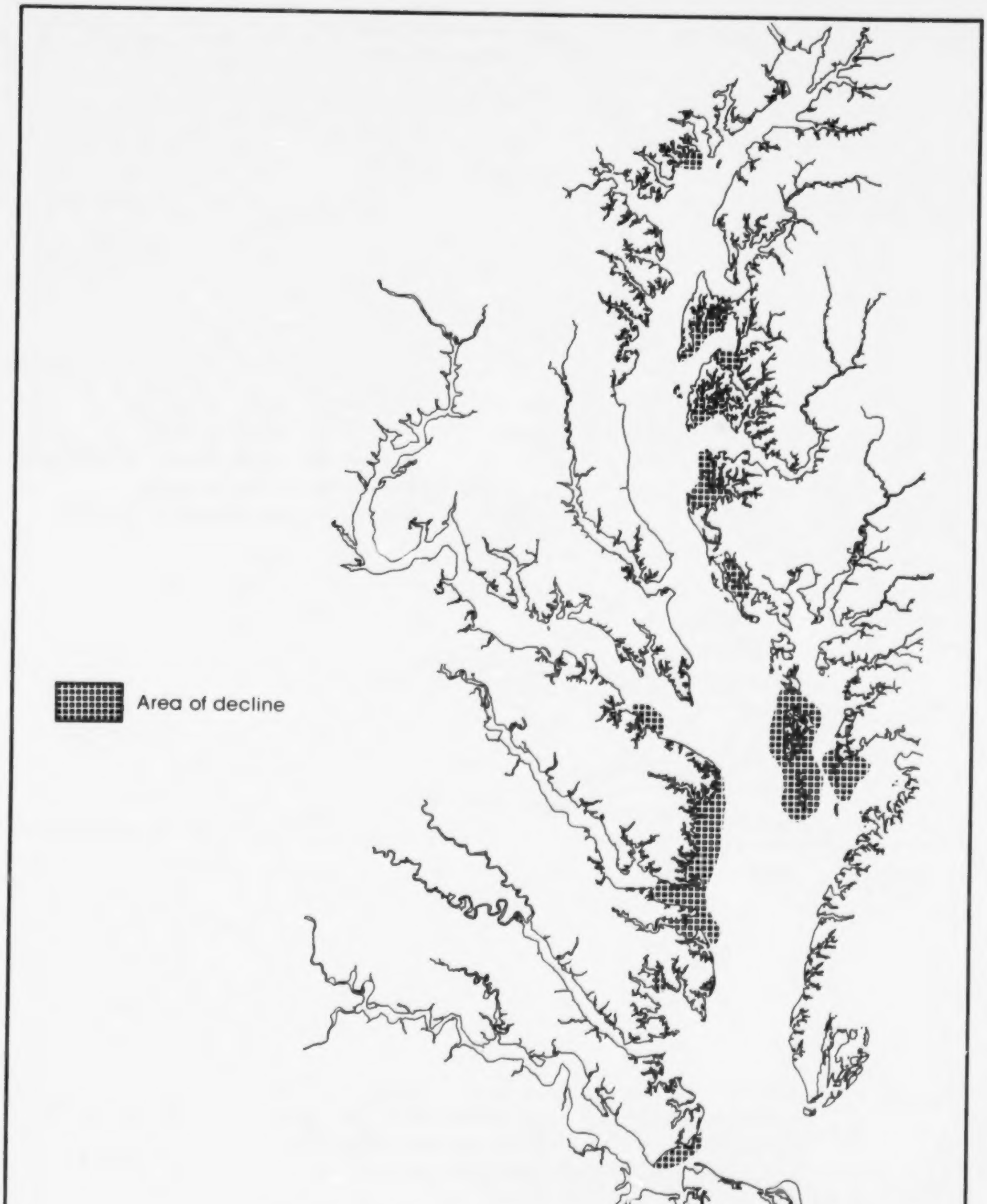

Figure 6. Area of submerged aquatic vegetation decline between 1975 and 1980 (after Orth et al. 1982). During this period, remaining SAV beds in some areas showed further reduction and fragmentation; major effects occurred in the Northern Neck, Eastern Bay, lower Choptank, and near Smith Island.

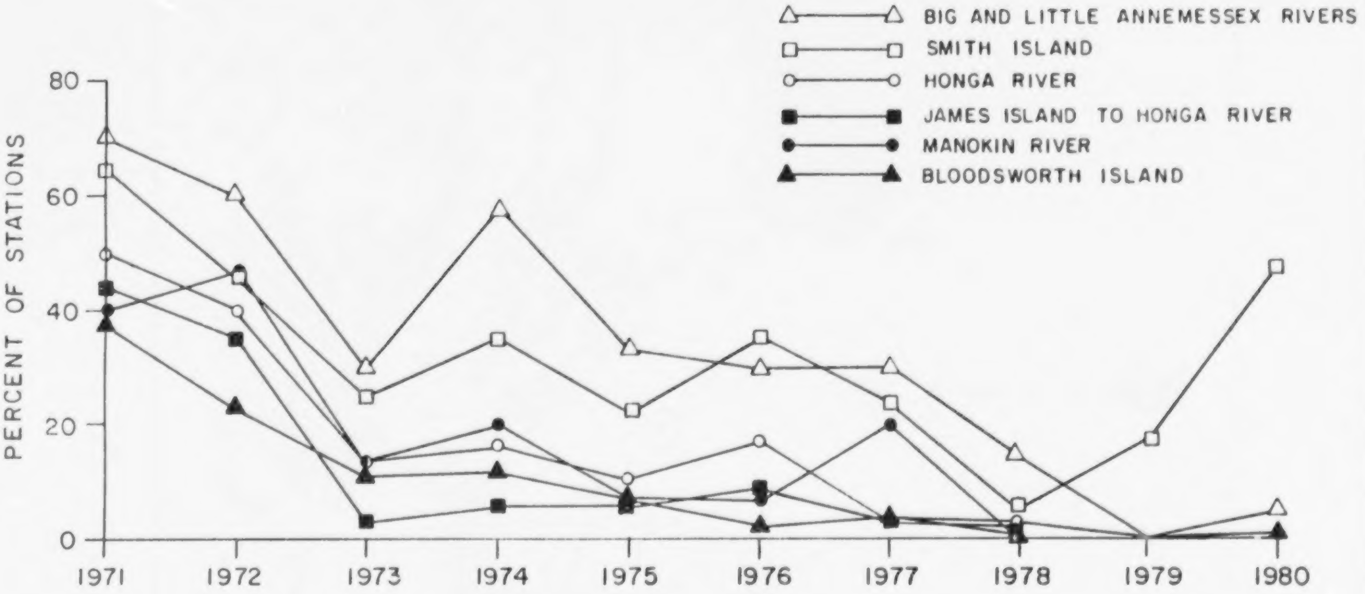

Figure 7. Trends in submerged aquatic vegetation occurrence in six areas in the middle Bay zone where SAV has markedly declined (data from Kerwin et al. 1977; unpublished data from Maryland's Department of Natural Resources) (after Orth et al. 1982).

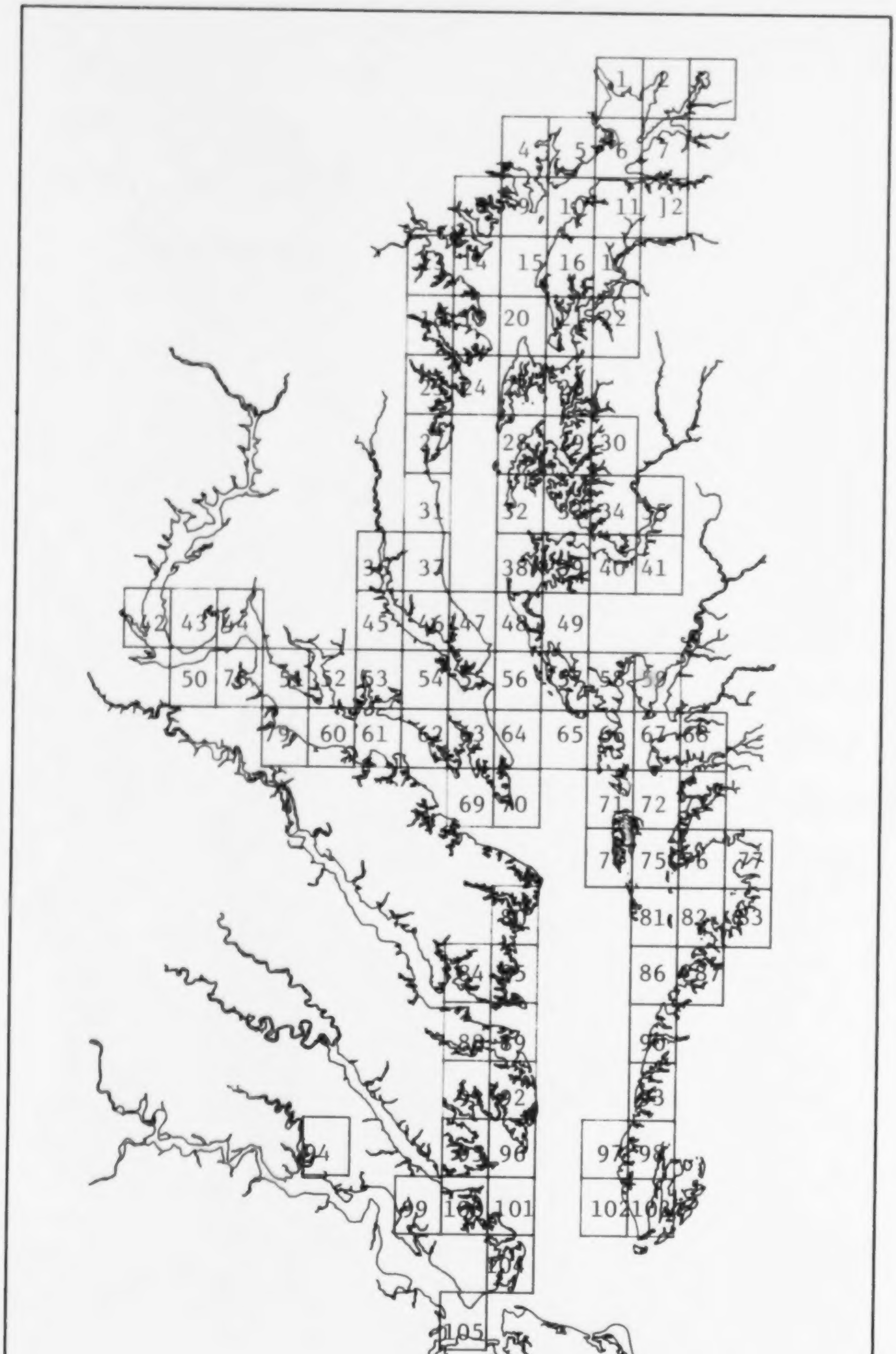
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Figure 8. United States Geological Survey (USGS) topographic quad areas used for aerial sampling of SAV (Orth et al. 1979; Anderson and Macomber 1980).

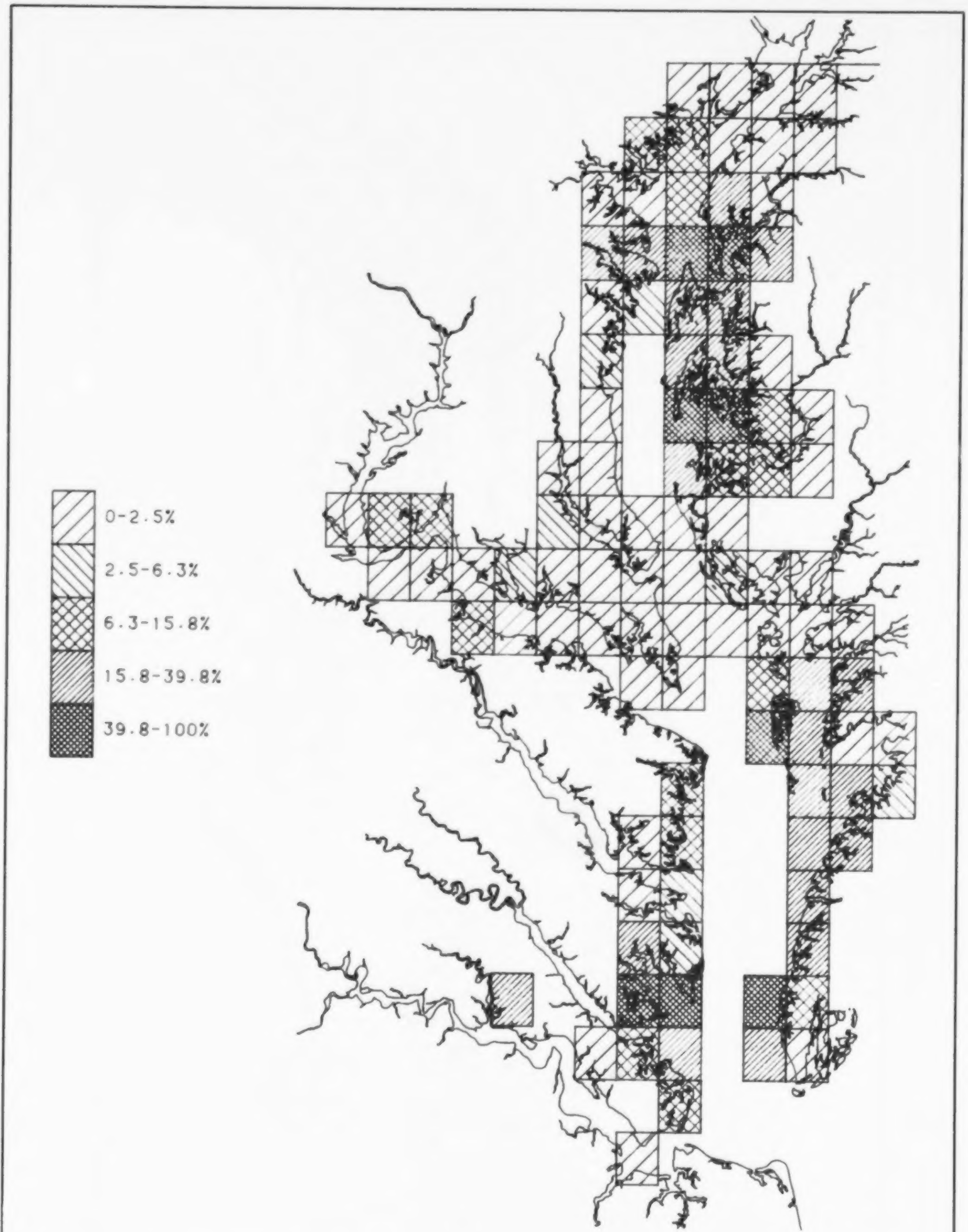
0-2.5%
2.5-6.3%
6.3-15.8%
15.8-39.8%
39.8-100%

Figure 9. Percent of expected submerged aquatic vegetation occupied in 1978 for each sampling area.

TABLE 15. BAY SEGMENTS SHOWING A DECLINE IN THE PERCENTAGE OF SITES VEGETATED (1971-1981), BY REGRESSION ANALYSIS*

Segment	Level of Significance
CB-5	.01
EE-1	.05
EE-3	.01
ET-5	.05
ET-8	.05
ET-9	.01
WT-7	.05
Sum of all segments sampled	.01
also CB-1	.10
WT-6	.10

*regression statistic: % sites vegetated/time

TABLE 16. BAY SEGMENTS SHOWING A STATISTICALLY SIGNIFICANT DECLINE IN DIVERSITY*

Segment	Level of Significance
CB-5	.01
EE-1	.05
EE-2	.05
EE-3	.01
ET-5	.05
ET-9	.01
WT-6	.01
WT-7	.05
Sum of all segments sampled	.01
also CB-1	.10
ET-8	.10

*By regression analysis of Shannon-Weaver Diversity index with time

TABLE 17. RANK OF SAV SAMPLING AREAS ACCORDING TO PERCENT OF EXPECTED HABITAT

Sampling Area (Fig. 9)	Potential Habitat (2 meter contour) acres	Expected Habitat (= 50 % of potential) acres	Distribution in 1978[1] acres	Distribution in 1978 / Expected Habitat %	Rank 6 = 0 - 2.5% 5 = 2.6 - 6.3% 4 = 6.4 - 15.8% 3 = 15.9 - 39.8% 2 = 39.9 - 75.9% 1 = 76 - 100%
1	13134	6567	273	4	5
2	4867	2433.5	14	1	6
3	2973	1486.5	2	0	6
4	3616	1808	26	1	6
5	3712	1856	0	0	6
6	8693	4346.5	2	0	6
7	4338	2169	12	1	6
8	5659	2829.5	222	8	4
9	6939	3469.5	469	14	4
10	3040	1520	23	1	6
11	1803	901.5	16	2	6
12	2054	1027	4	0	6
13	8057	4028.5	83	2	6
14	5105	2552.5	26	1	6
15	1861	930.5	74	8	4
16	1984	992	314	32	3
17	4330	2165	30	1	6
18	3245	1622.5	339	21	3
19	2812	1406	344	24	3
20	138	69	29	42	2
21	8152	4076	3100	76	2
22	1198	599	96	16	3
23	3719	1859.5	37	2	6
24	3624	1812	67	4	5
25	7928	3964	1269	32	3
26	6674	3337	1215	36	3
27	5558	2779	152	5	5
28	7017	3508.5	1040	30	3
29	5089	2544.5	904	36	3
30	1659	829.5	18	2	6
31	2468	1234	0	0	6
32	5767	2883.5	1181	41	2
33	6477	3238.5	1391	43	2
34	2487	1243.5	160	13	4
35	1713	856.5	0	0	6
36	2852	1426	4	0	6
37	1233	616.5	0	0	6
38	8254	4127	931	22	3
39	7258	3629	516	14	4

(continued)

TABLE 17. (continued)

Sampling Area (Fig. 9)	Potential Habitat (2 meter contour) acres	Expected Habitat (= 50 % of potential) acres	Distribution in 1978[1] acres	Distribution in 1978 / Expected Habitat %	Rank 6 = 0 - 2.5% 5 = 2.6 - 6.3% 4 = 6.4 - 15.8% 3 = 15.9 - 39.8% 2 = 39.9 - 75.9% 1 = 76 - 100%
40	3273	1636.5	121	7	4
41	870	435	0	0	6
42	4322	2161	0	0	6
43	1067	533.5	69	13	4
44	7134	3567	480	13	4
45	1882	941	34	4	5
46	2963	1481.5	2	0	6
47	2172	1086	7	0	6
48	5637	2818.5	0	0	6
49	2095	1047.5	0	0	6
50	1358	679	6	1	6
51	no data	--	no data	--	-
52	2426	1213	56	5	5
53	2503	1251.5	6	0	6
54	836	418	0	0	6
55	3614	1807	26	1	6
56	3362	1681	0	0	6
57	16569	8284.5	314	4	5
58	9265	4632.5	0	0	6
59	10255	5127.5	7	0	6
60	3261	1630.5	14	0	6
61	4289	2144.5	0	0	6
62	3266	1633	0	0	6
63	3369	1684.5	0	0	6
64	1283	641.5	0	0	6
65	2216	1108	2	0	6
66	14427	7213.5	163	2	6
67	1315	657.5	7	1	6
68	6703	3351.5	23	1	6
69	3578	1789	0	0	6
70	2365	1182.5	0	0	6
71	10593	5296.5	386	7	4
72	5965	2982.5	777	26	3
73	7439	3719.5	713	19	3
74	10300	5150	3666	71	2
75	10178	5089	1336	26	3
76	9931	4965.5	18	0	6
77	11674	5837	0	0	6
78	4388	2174	21	1	6
79	2517	1258.5	153	12	4

(continued)

TABLE 17. (continued)

Sampling Area (Fig. 9)	Potential Habitat (2 meter contour)	Expected Habitat (= 50 % of potential)	Distribution in 1978[1]	Distribution in 1978 / Expected Habitat %	Rank 6 = 0 - 2.5% 5 = 2.6 - 6.3% 4 = 6.4 - 15.8% 3 = 15.9 - 39.8% 2 = 39.9 - 75.9% 1 = 76 - 100%
	acres	acres	acres		
80	7944	3972	570	14	4
81	7037	3518.5	1001	28	3
82	12362	6181	1193	15	4
83	8194	4097	199	3	5
84	3983	1991.5	13	1	6
85	7070	3535	329	9	4
86	3629	1814.5	457	25	3
87	8954	4477	993	22	3
88	4956	2478	26	1	6
89	7037	3518.5	147	4	5
90	7386	3693	985	27	3
91	3500	1750	633	36	3
92	7499	3749.5	158	4	5
93	7858	3929	1247	32	4
94	1279	639.5	115	18	3
95	7639	3819.5	2015	53	2
96	8580	4290	2642	62	2
97	3384	1692	794	47	2
98	3853	1926.5	211	11	4
99	2133	1066.5	5	0	6
100	7355	3677.5	520	14	4
101	8836	4418	1277	29	3
102	1037	518.5	143	28	3
103	12536	6268	106	2	6
104	8862	4431	539	12	4
105	7381	3690.5	0	0	6

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[1] Data from Orth et al. 1979 and Anderson and Macomber 1980.

TABLE 18. RANK OF CBP SEGMENTS ACCORDING TO AGGREGATED SAMPLING AREAS

Segment	Sampling Areas Included	Rank of Sampling Areas respectively	Aggregated Rank *
ET-1	2	6	6
2	2,3	6,6	6
3	6,7	6,6	6
4	17,22,21,24,25	6,2,3,5,3	3
5	35,40,41	6,4,6	5
6	59	6	6
7	68	6	6
8	68	6	6
9	73	3	3
EE-1	25,26,28,29	3,3,3,3	3
2	32,33,38,39	2,2,3,4	3
3	76,77,82,83,66,67,72,75,81	6,6,4,5,6,6,3,3,3	4
CB-1	1,6	5,6	6
2	6,10	6,6	6
3	14,15,19,20,21	6,4,3,2,2	4
4	24,25,27,31,37,47,48,32	5,3,5,6,6,6,6,2	5
5	55,56,57,64,45,55,71,74,80,85	6,6,5,6,5,6,3,2,4,4	5
6	89,92	5,5	5
7	86,87,90,93,97,98,102,103	3,3,3,4,2,4,3,6	3
8	104	4	insuff. data
WT-1	4,5	6,6	6
2	4,9	6,5	6
3	8	6	6
4	8	4	4
5	13,14	6,6	6
6	18,19	3,3	3
7	18,19	3,3	3
8	23,24,27	6,5,5	5
WE-4	91,92,95,96,100,101	3,5,2,2,4,3	4

(continued)

TABLE 18. (continued)

Segment	Sampling Areas Included	Rank of Sampling Areas respectively	Aggregated Rank *
TF-1[1]	36	6	6
2[1]	--	6	6
3[2]	--	6	6
4[2]	--	6	6
5[1]	--	6	6
RET-1[1]	45	6	6
2	42,43,44,50,51,78	6,4,4,6,-,6	4
3[1]	--	6	6
4[1]	--	6	6
5[1]	--	6	6
LE-1	46,54,44	6,4,6	6
2	51,78,52,53,79,60,62,63	-,6,5,6,4,6,6,6	6
3	84,88,89	6,6,5	6
4	99,100	6,4	5
5	105	6	6

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[1] Areas lost before 1970; "6" ranking applied (Orth et al. 1982).

[2] Areas lost after 1970 (Orth et al. 1982).

*When a segment contained sampling areas having different ranks, areas having greater coverage of the habitat were weighted more heavily in developing an aggregated ranking.

TABLE 19. COMPARISON OF EXPECTED HABITAT RANKING RESULTS WITH RANKING OF MARYLAND SEGMENTS ACCORDING TO USFWS MBHRL DATA

Segment	Maximum % Sites Vegetated (year)[1]	1978 % Sites Veg.	1978 max. %	Rank	Comparison with Rank on Expected Habitat Scale[2]
CB-1	52.38 (1971)	3.45	7	6	6
CB-2	18.18 (1971)	0	0	6	6
CB-3	15.38 (1980)	11.54	75	3	5
CB-4	2.04 (1979)	0	0	6	6
CB-5	58.7 (1971)	0	0	6	6
EE-1	50.0 (1972)	28.57	57	3	4
EE-2	73.68 (1976)	29.31	40	4	3,5
EE-3	32.82 (1971)	4.62	14	5	6,6,4
ET-1	14.29 (1979)	0	0	6	6
ET-2	7.69 (1971)	0	0	6	6
ET-3	30.0 (1971)	0	0	6	6
ET-4	67.85 (1971)	46.43	68	3	6,3
ET-5	29.41 (1971)	5.56	19	5	6
ET-6	0	0	0	6	6
ET-7	0	0	0	6	6
ET-8	45.45 (1972)	0	0	6	6
ET-9	83.33 (1971)	18.18	21	4	5
LE-1	7.41 (1972)	0	0	6	6
RET-1	11.11 (1978)	11.11	100	2	6
TF-1	0	0	0	6	6
WT-1	0	0	0	6	6
WT-2	50.0 (1980)	0	0	6	5
WT-3	42.86 (1977)	0	0	6	6
WT-4	0	0	0	6	6
WT-5	14.29 (1977)	14.29	100	2	6
Wt-6	57.14 (1971)	14.29	25	4	4
WT-7	50.0 (1971)	33.33	66	3	4
WT-8	14.29 (1976)	0	0	6	6

[1] Data from USFWS/MBHRL (1971-1980)

[2] 0 - 2.5 % = 6; 15.9 - 39.8 % = 3;
2.6 - 6.3 % = 5; 39.9 - 75 % = 2;
6.4 - 15.8 % = 4; 76 - 100 % = 1.

SECTION 6
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SECTION 1

ADAPTING WATER/SEDIMENT QUALITY INFORMATION FOR COMPARISON TO LIVING RESOURCES

To facilitate comparison of toxicant levels in sediment or water column, we modified data presented in Chapter 1 to increase their biological applicability. This adjustment was done through use of a water quality survival envelope and a toxicity index.

WATER QUALITY CRITERIA AND SURVIVAL ENVELOPE SCREEN

Methodology

We determine tolerances of resource species toward various toxic substances from published information on bioassays showing both acute and sublethal effects. A list was compiled of the effects which included LC_{50} values (concentration of toxicant that kills 50 percent of the population), LC_{100} values (concentration that kills 100 percent of population), and EC_{50} values (concentration causing a certain effect, such as reduction in growth, in 50 percent of the population), for EPA priority pollutants, if sufficient toxicity information was available. (This list is included in Kaumeyer and Setzler-Hamilton 1982.) Because different life stages of a species may vary in sensitivity to toxic materials, toxicity information was organized into: egg (or embryonic), larvae, juvenile, and where appropriate, adult.

These levels were compared to the published EPA ambient water quality criteria, both 24-hour or "chronic" values (value should not be exceeded as a 24-hour average) and "anytime" or "acute" values (concentration should not be exceeded at any time). In the great majority of cases, these EPA criteria were stricter than published LC_{50} values for various Bay species. Where LC_{50} values were lower (i.e., the species was more sensitive), one-half the LC_{50} value was substituted. These values were used as threshold levels in screening against measured water column concentrations for each toxicant contained in the CBP data file.

Toxicants screened include heavy metals, organic chemicals, and total residual chlorine. Data for heavy metals needed some modification, as most had been recorded as "total metals," where the value included all forms (dissolved, particulate, and forms complexed to suspended sediment). In the environment only the dissolved, or ionic, fraction is usually biologically available and thus potentially toxic, at least to non-benthic species (U.S. EPA 1982a). The water quality criteria are based on "total recoverable metals;" under laboratory bioassay conditions; however, these typically represent inputs as salts of metals and, thus, probably exist mainly in the dissolved or ionic fraction.

Because national criteria may be unnecessarily stringent if applied to total metal measurements in waters where most of the forms are insoluble or strongly bound to particulates, estimates of the dissolved fractions were derived from data collected in the Bay mainstem by the

National Bureau of Standards (Kingston et al. 1982). In general, a major fraction of cadmium (Cd), copper (Cu), and nickel (Ni), exists as dissolved, while the opposite holds for zinc (Zn), lead (Pb), and chromium (Cr). In freshwater, (generally, the oligohaline zone) some forms show greater proportion in the particulate fraction or in the region of the turbidity maximum (Table 1).

Toxicity of metals varies with salinity, pH, hardness, and natural occurrence of chelating agents. Bay segments were grouped by long-term salinity average based on Stroup and Lynn (1963)(Table 2). Freshwater criteria were used for segments where long-term average salinities were less than 0.5 percent (Stroup and Lynn 1963). Oligohaline segments, where salinity may range between 0.5 and 5.0 ppt, but which are riverine in many of their chemical or physical features, were also screened using freshwater criteria. Also, many of their major biotic components are more closely allied to freshwater than to high salinity areas (Shea et al. 1980). Saline criteria were used for segments where annual salinity averages were greater than 5 ppt.

To estimate water hardness (ppm $CaCO_3$), which determines the actual freshwater criteria, we calculated means of hardness, as well as maximum and minimum values, from the CBP data base for freshwater and brackish segments (Table 3). Minimum hardness values were consistently less than 50 ppm in freshwater areas. For this reason, freshwater criteria for 50 ppm hardness were used in these segments. Brackish segments showed hardness values ranging from 100 to greater than 2000; freshwater criteria for 200 ppm hardness were used in these segments.

Total metal:dissolved metal ratios were calculated for "fresh," "brackish," and "saline" stations (based on previously discussed salinity criteria) for Cd, Cu, Ni, Zn, Pb, and Cr. Equations were developed, based on mean total:dissolved ratios, to estimate dissolved metals from "total" values (Table 1). In data sets where only total values were available, e.g., the Virginia and Maryland "106" data, these estimators were employed.

It should be emphasized that these are only estimates, not measured values; thus the results of the criteria screen are suggestive of problems, not definitive.

For total residual chlorine, recommended criteria from a 1983 draft EPA document were employed.[1] These guidelines were developed in a manner similar to that for the Ambient Water Quality Criteria documents. However, "instantaneous" concentrations (should never be exceeded) and "chronic" values (should not be exceeded as a 30-day average) were developed. These are:

Freshwater	
instantaneous	29.0 ug L^{-1}
30-day chronic	6.6 ug L^{-1}
Salt water	
instantaneous	25.0 ug L^{-1}
30-day chronic	5.7 ug L^{-1}

These values were screened against measured water column data from the CBP data base.

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[1] Personal communication: "Proposed Draft Water Quality Criteria for Total Residual Chlorine and Chlorine-Produced Oxidants," W. Brungs, EPA-Naragansett, 1983.

TABLE 1. ESTIMATES OF DISSOLVED METALS

[Where only "Total Metals: values exist (e.g., MD and VA "106" data), the following equations were used to estimate "Dissolved Metals." Letter refers to segment group listed in Table 2. (Source: Kingston et al. 1982)]

Metal	Equations	Group
Cadmium		
0.5 ppt	Diss = 0.60 Total	Group A
1 - 5 ppt	Diss = 0.73 Total	Group B
5 ppt	Diss = 0.87 Total	Group C
Copper		
0.5 ppt and 1 - 5 ppt	Diss = 0.32 Total	Group A & B
5 ppt	Diss = 0.57 Total	Group C
Nickel		
0.5 ppt and 1 - 5 ppt	Diss = 0.35 Total	Group A & B
5 ppt	Diss = 0.83 Total	Group C
Zinc		
0.5 ppt	Diss = 0.30 Total	Group A
1 - 5 ppt	Diss = 0.15 Total	Group B
5 ppt	Diss = 0.05 Total	Group C
Lead		
0.5 ppt	Diss = 0.04 Total	Group A
1 ppt	Diss = 0.30 Total	Group B & C
Chromium		
0.5 ppt	Diss = 0.07 Total	Group A
1 - 5 ppt	Diss = 0.04 Total	Group B
5 ppt	Diss = 0.02 Total	Group C

TABLE 2. BAY SEGMENTS GROUPED BY SALINITY BASED ON LONG-TERM AVERAGE VALUES FROM STROUP AND LYNN 1963

A. Freshwater (< 0.5 ppt)	TF-1,2,3,4,5 CB-1 ET-1,2,3 WT-1,2
B. Brackish (0.5 - ppt)	CB-2,3 RET-1,2,3,4,5 ET-4 WT-3,4
C. Saline (> 5 ppt)	CB-4,5,6,7,8 LE-1,2,3,4,5 EE-1,2,3 ET-5,6,7,8,9,10 WT-5,6,7,8 WE-4

TABLE 3. HARDNESS VALUES (as ppm $CaCO_3$) FOR REPRESENTATIVE TIDAL-FRESH AND OLIGOHALINE SEGMENTS

Segment	$\overline{X}$	Min.	Max.
CB-1	81.9	56	121
TF-1	535.4*	22	2,430*
TF-2	74.1	6	167
ET-1	56.0	(single observation)	
ET-2	145	52	540
ET-3	81	49	220
WT-2	73.1	58	111

* May represent an anomalous value.

Results

For heavy metals, estimates of dissolved concentrations exceeded water quality criteria in a number of areas. Relative to the number of observations, usually fewer than 10 percent were high enough to exceed acute criteria (Table 4). There are more violations of chronic criteria (Table 5); this is particularly true for Cu and Zn (Chapter 1). Most high values occurred in the lower reaches of tributaries and in the upper and mid-Bay. High values of Cd, Cr, and Zn have been measured in some tidal-fresh areas, such as the Potomac River and the Susquehanna Flats.

Relatively few exceedences by organic chemical criteria were recorded (Chapter 1). This probably reflects paucity of observations and limits of methodologies employed for routine monitoring. Those measured were primarily pesticides and were recorded in tributaries.

For total residual chlorine of 358 observations in (mainly) tidal-fresh areas, 67 percent exceeded the draft criteria. However, it should be emphasized that methodologies employed in measuring chlorine in the field often were not accurate at low ambient concentrations; many of the recorded values appeared to be limit-of-detection numbers.

Discussion

Because each measurement in the CBP data base represents a single observation, we have little feeling for the extent and duration of exposures. Similarly, variability in the field and laboratory measurements leads to a certain "margin of error" around the data upon which criteria are based. For example, differences of a factor of two in similarly derived LC_{50} numbers for a species would not be unexpected.[2] Thus, the magnitude of the excursion above the criterion (it exceeds the criterion by 100 percent, or 200 percent, for example) would perhaps be a more realistic assessment of potential damage. This analysis is being considered.

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[2] Personal Communication: "Variability in LC_{50} Responses of Organisms to Toxicants," W. Brungs, EPA-Naragansett, 1982.

TABLE 4. ACUTE HEAVY METAL VALUES FOR USE IN TABULATION OF FREQUENCY OF WATER QUALITY CRITERIA VIOLATIONS, IN ug L^{-1}. LETTER REFERS TO BAY SEGMENT GROUP

Metal	Salinity (ppt) 0.5 (A)	 0.5 - 5.0 (B)	 5.0 (C)
Cd	1.0*	6.3	59.0
Cr^{+3}	2200.	9900.	5150.
Cr^{+6}	21.0	21.0	1260.
Cu	12.0	43.0	23.0
Ni	1100.	3100.	140.
Pb	79.	400.	334.0
Hg	-	-	3.7
Zn	100.0*	570.0	170.0

* 1/2 LC_{50} value for striped bass larvae.

TABLE 5. CHRONIC HEAVY METAL VALUES FOR USE IN TABLULATION OF FREQUENCY OF WATER QUALITY CRITERIA VIOLATIONS, IN ug L^{-1}. LETTER REFERS TO BAY SEGMENT GROUP

Metal	Salinity (ppt) 0.5 (A)	 0.5 - 5.0 (B)	 5.0 (C)
Cd	0.012	0.051	4.5
Cr^{+6}	0.29	0.29	18.0
Cu	5.6	5.6	4.0
Ni	56.0	160.0	7.1
Pb	0.75	20.0	25.0*
Hg	-	-	0.025
Zn	47.0	47.0	58.0

* No EPA value available. Based on chronic toxicity to mysid shrimp.

A TOXICITY INDEX FOR METALS IN BED SEDIMENTS

Introduction

A Contamination Index is presented in Chapter 1. This index estimates the enrichment of a suite of heavy metals relative to expected natural concentrations in bed sediments:

$$C_I = \sum_{i=1}^{i=6} \frac{Co_i - Cp_i}{Cp_i} = \sum_{i=1}^{i=6} Cf_i$$

Where Co = the surface sediment concentration of a given metal,
C_p = the predicted concentration, and
C_f = the concentration factor.

Calculation of the predicted concentration normalizes for differences in metal affinity for various sediment grain sizes and organic content. Thus the C_I is a dimensionless number only indirectly related to actual concentration in the sediment.

It is tempting to modify the index so that it can better predict potential biological impact of contaminated sediments. However, it has not always been easy to demonstrate direct relationships between the concentration of toxicants in bed sediments and the effects on organisms. Bioavailability of metals appears to be related not only to gross concentration, but to the forms in which they are present. Their availability also seems to depend on geochemical features of the sediments and of the species of organisms impacted (Ayling 1974, Neff et al. 1978, Ray et al. 1981). For these reasons, extensive sediment bioassay and elutriate testing are needed to assess the actual effects of contaminants. In addition, processes affecting bioavailability require much further study. However, progress in this direction is only in initial stages; we are not ready, for example, to try to formulate "sediment quality criteria" analogous to the EPA Water Quality Criteria discussed above.[3]

Mindful of these many caveats, we have made an initial attempt to make the C_I more meaningful ecologically. At this writing, only water-column-derived estimates of toxicity are available. Making the conceptual jump that metals most toxic in the water column will prove most toxic in bed sediments appears not unreasonable, but should, nevertheless, be approached with some caution. If a toxicity index, weighted by relative water-column toxicity, proves a better predictor of observed effects on organisms than the non-weighted C_I, then we may be heading in the right direction. (This is examined further in the section on benthic organisms.) Eventual availability of sediment-based criteria will allow us to refine this index further.

---

[3] Personal Communication: "Status of Sediment Toxicity Information," W. Brungs, EPA-Naragansett, 1982.

The toxicity index closely relates to the contamination index and is defined as:

$$T_I = \sum_{i=1}^{i=6} \frac{M_1}{M_i} Cf_i$$

where M_i = the "acute" anytime EPA criterion for any of the metals,
but M_1 is always the criterion value for the most toxic of the six metals.

The "acute" anytime EPA criterion is the concentration of a material that may not be exceeded in a given environment at any time. This value may be different for different environments. The criterion values are calculated by standardized procedures using data from in-house EPA studies and from published scientific literature (U.S. EPA 1982a).

EPA criterion values for each of the six metals are shown in Table 6; the ratios of the value for the most toxic metal to each of the other metals appear in Table 7. The toxicity index was calculated for every station where the Contamination Index was calculated. Each station was given an average salinity value based upon its geographical location and available salinity data (Stroup and Lynn 1963). Because the toxicity of metals is often greater in fresh water than in salt water, we characterized each station by its minimum salinity. Bottom salinities were used in every case. Freshwater stations were those with salinities less than 0.5 ppt, and these were assigned criterion values for freshwater at 50 ppm hardness. Brackish stations were those with salinities between 0.5 and 5.0 ppm, and these were assigned criterion values for freshwater with a hardness of 200 ppm. Stations with salinities greater than 5.0 ppt were assigned criterion values for saltwater. (See discussion in the section on Water Quality Criteria above.)

RESULTS AND DISCUSSIONS

Much of the discussion in the chapters of this report is based on a division of the Chesapeake Bay and its tributaries into spatial segments. Accordingly, values for the toxicity index have been analyzed in a similar manner (Figure 1). Not surprisingly, the segment showing the highest mean toxicity index is that encompassing the Patapsco River and Baltimore Harbor. Clearly, this area is highly impacted by industrial activity and has been characterized as highly polluted with metals based on the Contamination Index presented in Chapter 1. Other segments with high mean values for the toxicity index include the lower James River, the upper York River up to the confluence of the Mattaponi and Pamunkey Rivers, and the very upper reach of Chesapeake Bay near northeast Maryland. Somewhat less contaminated are the main Bay adjacent to Baltimore and the lower Rappahannock River. The main Bay south of Baltimore and the entire Potomac River show little evidence of contamination with toxic metals; the main Bay south of the Rappahannock and the entire eastern shore south of the Nanticoke River are more or less pristine in terms of toxic metals.

However, the analysis of metal pollution using mean values for the toxicity index in each segment can occasionally lead to incorrect conclusions. For example, the high mean value for the toxicity index in

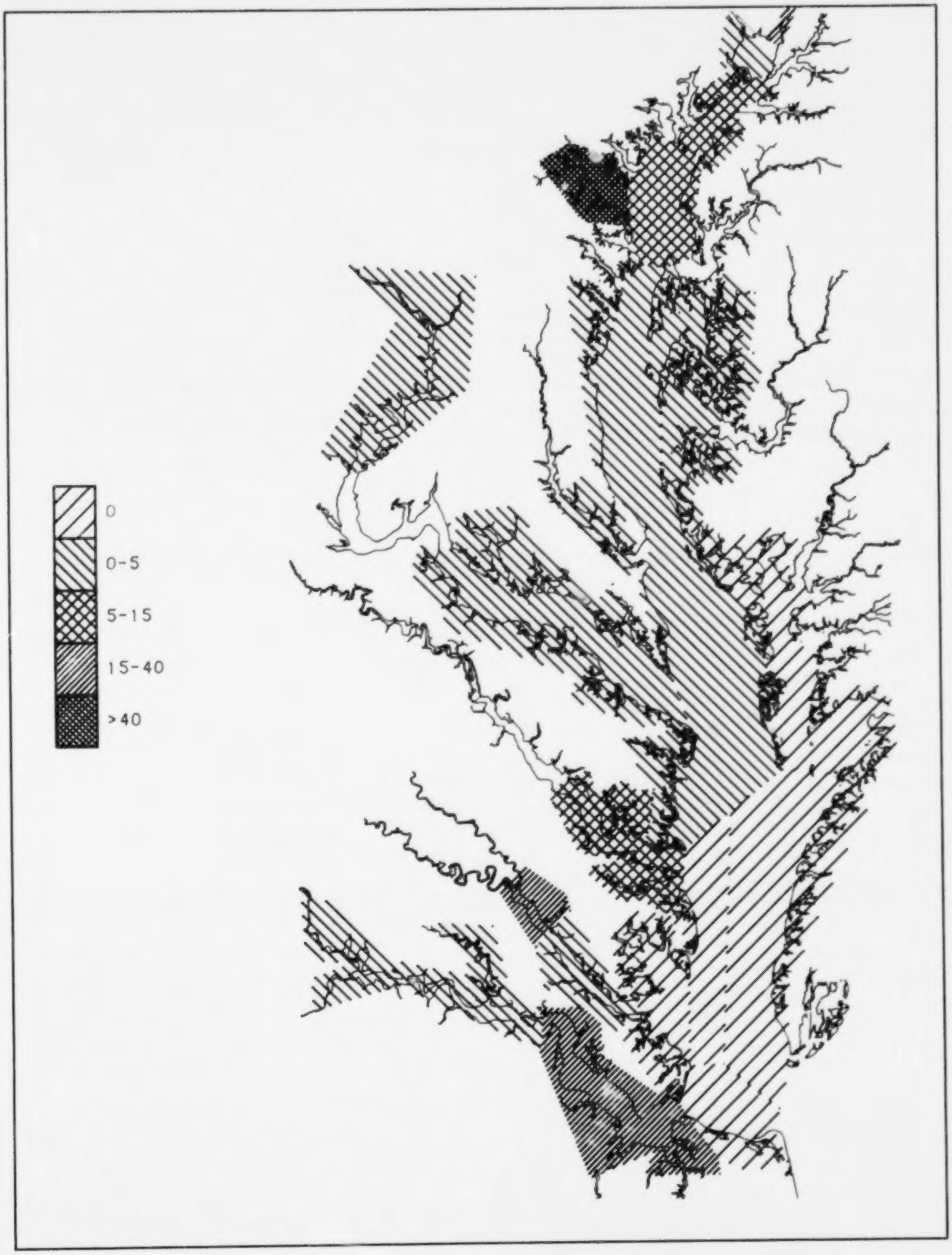
0
0-5
5-15
15-40
>40

Figure 1. The toxicity index (T_I) averaged over Chesapeake Bay segments.

TABLE 6. ACUTE CRITERIA: LEVELS OF EACH OF SIX METALS THAT MAY NOT BE EXCEEDED AT ANY TIME AS ESTABLISHED BY THE U.S. ENVIRONMENTAL PROTECTION AGENCY. VALUES ARE TOTAL RECOVERABLE METAL IN ug L^{-1}

Metal	Salinity (ppt)		
	0.5	0.5 x 5.0	5.0
Cadmium	1.5	6.3	59.0
Chromium (+3)	2200.0	9900.0	5150.0*
Copper	12.0	43.0	23.0
Lead	74.0	400.0	344.0*
Nickel	1100.0	3100.0	140.0
Zinc	180.0	570.0	170.0

*No EPA criterion exists. Value shown is 0.5 x LC_{50} for most sensitive species tested: striped bass larvae.

TABLE 7. RATIO OF EPA CRITERION (ACUTE) FOR MOST THE TOXIC METAL TO EACH OTHER METAL

Metal	Salinity (ppt)		
	0.5	0.5 x 5.0	5.0
Cadmium	1.0	1.0	3.9×10^{-1}
Chromium (+3)	6.8×10^{-4}	6.4×10^{-4}	4.5×10^{-3}
Copper	1.2×10^{-1}	1.4×10^{-1}	1.0
Lead	2.0×10^{-2}	1.8×10^{-2}	6.7×10^{-2}
Nickel	1.4×10^{-4}	1.7×10^{-2}	1.6×10^{-1}
Zinc	8.3×10^{-3}	9.4×10^{-2}	1.4×10^{-1}

the lower James River is the result of extremely high values at a few stations, while the majority of stations in the area are relatively uncontaminated with highly toxic metals (Table 8). Therefore, an analysis of the values for the toxicity index at individual stations without regard to segment boundaries provides a better perspective of the problem. A contour map of toxicity indices using logarithmic intervals again shows a high level of contamination in Baltimore Harbor, but with the apparently associated high indices in the adjacent main Bay, restricted largely to the axis of the Bay (Figure 2). Additionally, the sediments in much of the lower James River are relatively uncontaminated by toxic metals; only those sediments off Norfolk and near Portsmouth are highly contaminated. Comparison of contour maps of C_I versus T_I reveals areas of similarity, as would be expected. In general, however, the toxicity index map shows more details of structure and variation within an area than does the C_I map. Areas of greatest toxicity, such as Baltimore Harbor, an area extending northward to the Susquehanna Flats, the Northeast River, the lower Rappahannock, upper York, and the Elizabeth River, are also most contaminated using the C_I. In addition, the lower Patuxent River and several smaller tributaries of the lower James have high toxicity indices. Moderately high values of the T_I occupy the central and upper Bay main stem and lower reaches of most western shore tributaries, except the James River. In general, this pattern follows the distribution of finer sediments in Chesapeake Bay, which is not unexpected, as heavy metals are associated with the silt and clay fraction of the substrate.

Though a contour map based on logarithmic intervals allows a general analysis of metal contamination of the Bay's sediments, the toxicity index at stations within a contour interval can vary greatly, especially within the interval containing the highest values. Toxicity indices for stations in Baltimore Harbor range from 3.2 to 2691.4 and reflect considerable differences in the expected toxicity of the sediments.

TABLE 8. TOXICITY INDICES FOR DIFFERENT SPATIAL SEGMENTS OF CHESAPEAKE BAY AND ITS TRIBUTARIES. INDEX IS BASED ON CONCENTRATION AND RELATIVE TOXICITY OF SIX METALS (Cd, Cr, Cu, Ni, Pb, Zn) IN SEDIMENT SAMPLES. (SEE FIGURE 1 FOR LOCATION OF SEGMENTS)

Segment	Number of Stations	Mean	Standard Deviation	Maximum Value	Minimum Value
James LE-5	31	30.4	39.8	131.4	0.0
James RET-5	1	1.8			
James TF-5	3	3.8	2.7	1.5	6.8
Lower Bay CB-6	10	0.0			
Lower Bay CB-7	28	0.0			
Lower Eastern Shore EE-3	1	0.0			
Mid-Bay CB-4	37	4.0	3.6	11.2	0.0
Mid-Bay CB-5	27	1.5	4.2	18.1	0.0
Eastern Shore EE-1	1	2.6			
Eastern Shore EE-2	1	2.3			
Patuxent LE-1	3	2.3	2.9	4.7	0.0
Potomac LE-2	6	2.5	2.8	6.5	0.0
Rappahannock LE-3	8	12.7	12.7	31.9	0.0
Upper Bay CB-1	14	4.1	5.6	19.9	0.0
Upper Bay CB-2	7	8.3	4.4	15.6	1.0
Upper Bay CB-3	15	8.7	6.5	21.2	0.0
Upper Eastern Shore ET-1	1	19.7			
Western Tributaries WT-5	159	61.4	218.4	2691.4	3.2
York LE-4	3	1.5	4.0	6.1	0.0
York RET-4	2	32.8		33.2	32.6
York WE-4	4	0.0			

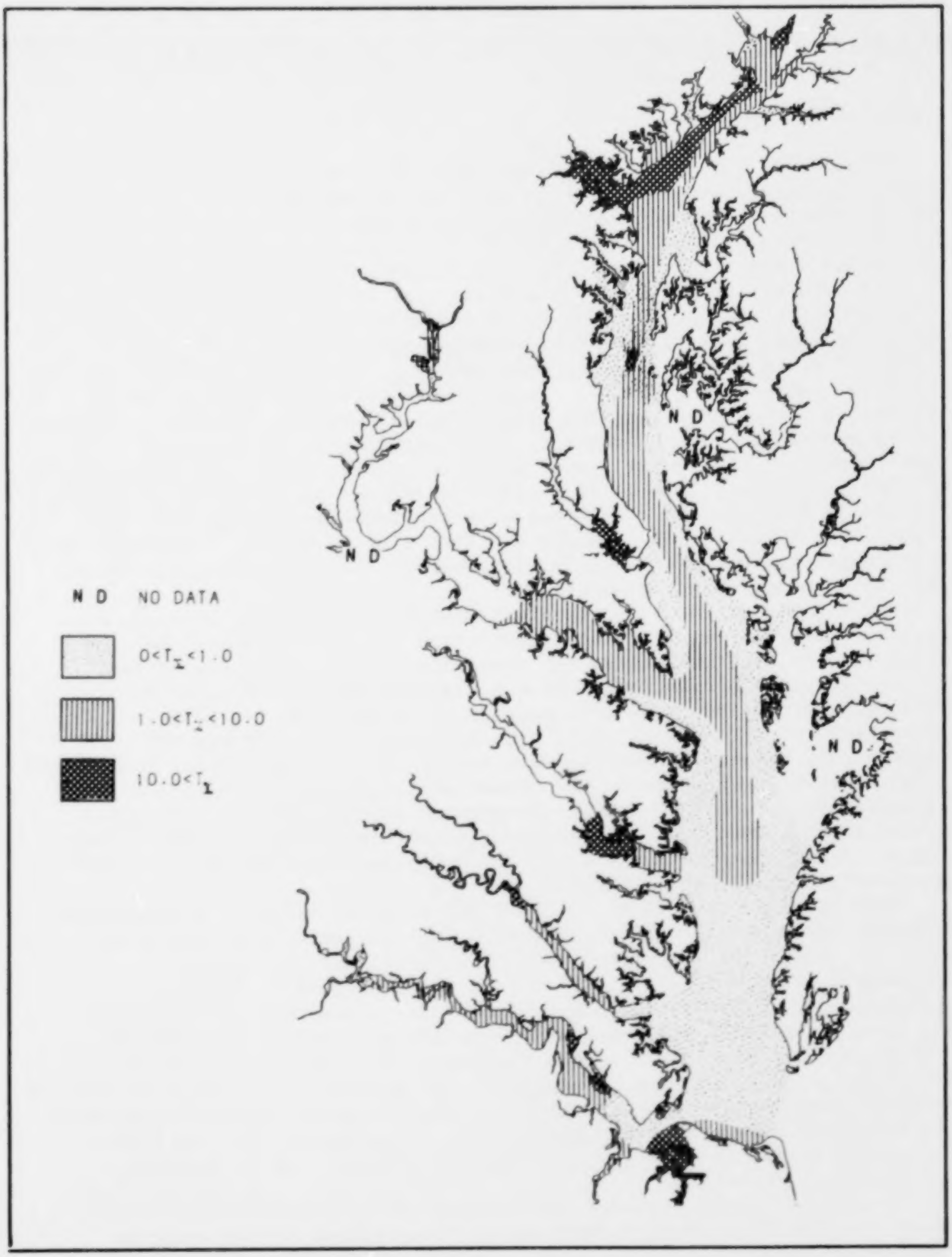
N D
NO DATA
$0<T_I<1.0$
$1.0<T_I<10.0$
$10.0<T_I$
N D
N D
N D

Figure 2. Toxicity index of surface sediments in Chesapeake Bay.

SECTION 2
ANALYSES FOR COMPARING WATER QUALITY WITH SAV TRENDS

CORRELATION ANALYSIS

Because SAV declines are hypothesized to be related to some water quality factors, certain variables were tested (by correlation analysis) against vegetation abundance in those Chesapeake Bay segments where sufficient data existed. A parametric test (Pearson's correlation coefficient) and a non-parametric test (Spearman's rho) were used. The 11-year data set from the Maryland Department of Natural Resources and the USFWS on SAV abundance was used as an estimator of vegetation abundance. Among the water quality variables screened were: TN, nitrate, TP, dissolved inorganic phosphorus, chlorophyll a, turbidity, Secchi depth, DO, salinity, temperature, and pH. There were compared to total percent vegetation using annual, spring, summer means, and 95th percentile values for each variable in each segment. Data were tested using direct comparison of a particular year's SAV data against water quality variables of that year (e.g., 1971 to 1971, 1972 to 1972). In addition, under the hypothesis that growing conditions of a previuous year might have a significant effect on SAV success the next growing season, vegetation data were tested agains water quality variables for the preceding year (e.g., 1971 SAV against 1970 variables).

The results of the analyses are presented in Table 9. Overall, the greatest number of significant correlations were found between SAV and nutrients; DO, pH, turbidity, and temperature also showed significant relationships. Correlations were all negative between SAV and the 95th percentile of TN, NO_3, the 95th percentile of NO_3, and the 95th percentinle of IPF; the majority were negative between TN and IPF. Correlations between TP and the 95th percentile were positive. Chlorophyll a, DO, salinity, and temperature showed both negative and positive correlations. Turbidity usually correlated negatively with SAV, while Secchi depth showed mostly positive relationships. The variable pH was always correlated positively with SAV, while the 95th percentile showed consistent negative relationships.

When assessed by region, the main Bay segments (CB 1-5) demonstrated negative correlations with TN, NO_3, and IPF and positive correlations with TP. Turbidity (negative), salinity (positive), temperature (negative), and pH (positive) were other major variables showing correlations. Overall, TN, NO_3, and the 95th percentile of NO_3 showed the most significant relationships. Eastern Shore areas show the most significant correlations with NO_3 (negative, the 95th percentile TP (positive), turbidity (mostly negative), DO (mixed), the 95th percentile of salinity (negative) and pH (positive). Western Shore segments (including the Patuxent) have the fewest significant correlations, but the 95th percentile of IPF (negative), chlorophyll a (mixed) and DO (mostly positive) can be noted.

In general, these analyses simply show correspondence of trends in water quality and submerged vegetation. They should not be taken as demonstrations of cause-and-effect. However, most are consistent with the hypothesis that increased nutrients and turbidity are linked to observed declines in SAV.

TABLE 9. RESULTS OF CORRELATION ANALYSES OF WATER QUALITY VARIABLES AGAINST SUBMERGED AQUATIC VEGETATION (SAV DATA FROM MARYLAND DNR AND THE U.S. FWS 1971 to 1981). MARYLAND ONLY. P = PEARSON'S CORRELATION S = SPEARMAN'S CORRELATION

Segment	Analysis	Time Period	Water Quality Variable	Correlation Coefficient	P F	n
CB-1	P	annual	NO_3	-0.92	0.005	9
	S	"	TN	0.79	0.006	10
	S	"	NO_3	-0.84	0.004	9
	P	annual lag	temperature	-0.69	0.03	10
	P	"	NO_3	-0.90	0.03	5
	S	"	temperature	-0.71	0.03	9
	P	summer lag	DO	-0.85	0.004	9
	S	"	95-salinity	0.62	0.05	10
	P	summer	NO_3	-0.94	0.02	5
	S	"	salinity	0.77	0.04	7
	P	spring lag	pH	0.81	0.05	6
	S	"	pH	0.93	0.001	6
CB-2	P	annual	TN	-0.71	0.02	10
CB-3	P	annual lag	NO_3	-0.74	0.015	10
	S	"	NO_3	-0.76	0.01	10
	P	"	IPF	-0.75	0.01	10
	P	summer	95-TN	-0.81	0.005	10
	S	"	95-TN	-0.86	0.001	10
	P	summer lag	95-TN	-0.81	0.004	10
	S	"	95-TN	-0.87	0.001	10
	P	spring lag	IPF	-0.62	0.05	10
CB-4	S	annual lag	turbid	-0.76	0.03	8
	P	summer	95-pH	-0.67	0.04	10
	S	"	95-pH	0.69	0.02	10
	P	summer lag	95-pH	0.66	0.04	10
	S	"	95-pH	-0.70	0.03	10
	P	spring lag	TN	0.75	0.03	8
CB-5	P	annual	95-TN	-0.87	0.002	9
	P	"	95-TP	0.64	0.03	11
	S	"	95-TN	-0.77	0.01	9
	S	"	95-salinity	0.61	0.04	11
	P	"	95-DO	0.69	0.02	10
	P	"	TN	-0.83	0.005	9
	P	"	TP	0.72	0.02	10
	S	"	TN	-0.69	0.04	9
	S	"	DO	0.68	0.03	10
	S	"	turbid	-0.84	0.04	6
	S	"	temperature	0.62	0.05	10
	P	annual lag	95-TN	-0.83	0.006	9
	P	"	95-TP	0.64	0.03	11

(continued)

TABLE 9. (continued).

Segment	Analysis	Time Period	Water Quality Variable	Correlation Coefficient	P F	n
	S	"	95-TN	-0.78	0.014	9
	S	"	95-DO	0.61	0.04	11
	S	"	turbid	-0.84	0.04	6
	P	spring	95-TN	-0.77	0.01	9
	S	"	95-salinity	0.64	0.03	11
	P	"	TN	-0.84	0.005	9
CB-5	S	spring	TN	-0.74	0.02	9
	P	summer	95-TN	-0.78	0.02	8
	S	"	95-TN	-0.83	0.01	8
	P	spring lag	95-TN	-0.74	0.02	8
	P	"	95-temperature	-0.86	0.001	11
	S	"	95-temperature	-0.71	0.015	11
	P	summer lag	95-TN	-0.77	0.03	8
	S	"	95-TN	-0.78	0.02	8
	P	"	turbidity	-0.73	0.04	8
	P	"	Secchi	0.95	0.001	8
	P		temperature	-0.88	0.001	10
EE-1	P	annual lag	95-DO	-0.70	0.05	8
	P	"	pH	0.75	0.05	7
	S	"	TP	-0.75	0.05	7
	S	"	salinity	-0.65	0.05	9
	P	"	salinity	-0.68	0.04	9
	P	spring	95-TN	-0.99	0.006	4
	P	spring lag	95-TN	-0.99	0.006	4
EE-2	P	annual	NO_3	-0.94	0.02	5
	P	summer lag	95-salinity	-0.85	0.03	6
	P	annual lag	pH	0.97	0.03	4
EE-3	P	annual	95-turbid	-0.91	0.01	6
	P	"	turbid	-0.96	0.002	6
	P	"	pH	0.79	0.03	7
	S	"	turbid	-0.94	0.005	6
	S	"	pH	0.79	0.04	7
	P	annual lag	NO_3	-0.74	0.05	7
	P	"	turbid	-0.96	0.002	6
	P	"	salinity	0.76	0.03	8
	P	"	pH	0.89	0.007	7
	S	"	NO_3	-0.79	0.04	7
	S	"	turbid	-0.94	0.005	6
	S	"	salinity	0.76	0.03	6
	S	"	pH	0.93	0.003	7
	P	spring	95-Chl a	0.91	0.03	5
	S	"	95-Chl a	0.90	0.04	5

(continued)

TABLE 9. (continued).

Segment	Analysis	Time Period	Water Quality Variable	Correlation Coefficient	P	F	n
	P	spring lag	95-Chl a	0.91	0.03		5
	P	summer	turbid	-0.94	0.004		6
	P	"	DO	0.95	0.001		7
	P	"	pH	0.88	0.22		6
	S	"	turbid	-0.94	0.005		6
	S	"	DO	0.82	0.02		7
	S	"	pH	0.82	0.04		6
	P	summer lag	NO_3	-0.96	0.002		6
	P	"	DO	0.95	0.001		7
	P	"	temperature	-0.84	0.01		8
	S	"	DO	0.75	0.05		7
ET-4	P	annual	95-NO_3	-0.62	0.06		10
	P	"	95-temperature	0.62	0.04		11
	S	"	95-NO_3	-0.63	0.05		10
	S	"	95-temperature	0.77	0.006		11
	P	"	DO	-0.83	0.04		6
	P	"	temperature	0.77	0.006		11
	S	"	temperature	0.80	0.003		11
	P	"	chl a	0.99	0.01		4
	S	"	turbid	0.70	0.04		5
	P	annual lag	95-NO_3	-0.62	0.06		10
	P	"	95-temperature	0.63	0.04		11
	S	"	95-temperature	-0.63	0.05		10
	S	"	95-temperature	0.77	0.04		11
	P	"	95-DO	-0.63	0.04		11
	S	"	95-DO	-0.63	0.04		11
	S	"	temperature	0.64	0.05		10
	P	spring	95-DO	-0.90	0.001		7
	P	"	95-salinity	-0.73	0.04		8
	S	"	95-DO	-0.83	0.02		7
	P	"	salinity	-0.76	0.03		8
	P	"	pH	-0.81	0.03		7
	P	"	DO	-0.83	0.02		7
	S	"	NO_3	-0.90	0.04		5
	S	spring lag	95-DO	-0.75	0.05		7
	P	"	95-salinity	-0.73	0.04		8
	P	"	95-DO	-0.88	0.01		7
	S	"	TN	-0.87	0.05		5
	P	"	IPF	-0.98	0.02		4
	P	"	NO_3	-0.82	0.05		6
	P	summer	95-TP	0.72	0.04		8
	P	"	DO	-0.77	0.03		8

(continued)

TABLE 9. (continued).

Segment	Analysis	Time Period	Water Quality Variable	Correlation Coefficient	P F	n
	S	"	TP	0.72	0.04	8
	S	"	temperature	0.33	0.25	10
	P	summer lag	95-TP	0.81	0.01	9
	S	"	95-TP	0.66	0.05	9
	S	"	NO_3	-0.87	0.05	5
	S	"	pH	0.67	0.05	4
	P	"	TP	0.81	0.01	8
	P	"	Secchi	-0.91	0.05	4
	S	"	Secchi	0.95	0.05	4
	P	"	temperature	-0.73	0.02	10
ET-5	P	annual	DO	-0.74	0.01	10
	P	"	temperature	0.71	0.01	11
	S	"	temperature	0.70	0.02	11
	P	"	turbid	0.74	0.02	9
	S	"	DO	-0.70	0.02	10
	P	annual lag	95-salinity	-0.61	0.05	11
	P	"	TP	0.74	0.02	9
ET-5	P	annual lag	chl a	-0.89	0.003	8
	P	"	turbid	0.72	0.04	8
	S	"	chl a	-0.81	0.01	8
	S	"	IPF	0.69	0.05	8
	P	spring	95-salinity	-0.62	0.05	10
	P	"	NO_3	-0.74	0.06*	7
	S	"	NO_3	-0.74	0.06*	7
	S	"	IPF	-0.74	0.06*	7
	S	"	turbid	-0.72	0.02	9
	P	spring lag	salinity	-0.72	0.02	9
	S	"	pH	0.91	0.03	5
	P	summer	95-turbid	0.79	0.02	8
	P	"	95-IPF	-0.72	0.04	8
	S	summer lag	95-TP	0.67	0.05	9
	S	"	95-turbid	0.69	0.04	9
	P	"	DO	0.74	0.02	9
	P	"	TN	0.82	0.04	6
	S	"	TN	0.84	0.04	6
	S	"	chl a	-0.84	0.04	6
	S	"	IPF	0.81	0.05	6
LE-1	P	annual	chl a	0.95	0.02	5
	S	"	chl a	0.89	0.04	5
	S	"	temperature	-0.94	0.005	6
	P	annual lag	IPF	0.98	0.003	5
	S	"	chl a	0.89	0.04	5

(continued)

TABLE 9. (continued).

Segment	Analysis	Time Period	Water Quality Variable	Correlation Coefficient	P F	n
	P	spring	chl a	0.99	0.01	3
	P	summer	TP	0.89	0.04	3
	S	"	chl a	0.94	0.02	5
	P	summer lag	DO	-0.89	0.04	5
	S	"	TP	0.99	0.01	4
WT-2	P	annual	95-IPF	-0.83	0.02	7
	P	"	IPF	-0.79	0.03	7
	P	"	pH	-0.81	0.05	6
	P	annual lag	DO	-0.89	0.01	7
	S	"	DO	-0.93	0.003	7
	S	"	chl a	0.83	0.04	6
	P	"	95-DO	-0.79	0.03	7
	S	"	95-IPF	-0.83	0.02	7
	P	spring	95-turbid	0.95	0.05	4
	P	spring lag	95-turbid	0.98	0.01	4
	P	summer	95-IPF	-0.90	0.01	6
	S	"	95-IPF	-0.91	0.01	6
	P	summer lag	95-pH	-0.89	0.04	5
WT-3	P	annual	95-turbid	-0.79	0.06*	6
	P	annual lag	95-TN	-0.87	0.05	5
	S	spring lag	turbid	-0.95	0.05	4
	P	summer lag	chl a	-0.78	0.06*	6
WT-5	P	annual	95-chl a	-0.75	0.04	8
	P	"	95-Secchi	0.75	0.04	7
	S	"	95-chl a	-0.77	0.02	8
	P	"	TN	-0.77	0.04	7
	S	"	TN	-0.85	0.01	7
	P	"	DO	0.65	0.04	10
	S	"	DO	0.72	0.02	10
	P	annual lag	95-chl a	-0.77	0.02	8
	P	"	salinity	0.92	0.03	5
	P	"	Secchi	0.81	0.05	6
	S	"	Secchi	0.88	0.02	6
	P	spring	DO	0.73	0.02	10
	S	"	DO	0.70	0.02	10
	S	summer	95-NO$_3$	-0.86	0.03	6
	P	"	DO	0.77	0.02	8
	P	"	salinity	-0.,67	0.05	9
	S	"	DO	0.70	0.05	8
	P	summer lag	salinity	-0.87	0.003	9
	P	"	pH	0.75	0.05	7

*P = 0.06; not statistically significant at the 95 percent level, but included here for possible ecological significance.

Multiple Regressions Analysis

To achieve better insight into the contribution of water quality variables to SAV abundance, we used multivariate regression analysis to identify factors that best explained observed vegetation trends. A stepwise least-squares multiple regression procedure was used, employing the Statistical Analysis System (SAS) package (SAS Institute Inc., SAS Circle, Box 8000, Cory, NC 27511). A relatively low level of confidence was chosen for entry into the model (80 percent) to include all possible predictor vectors in the initial screening process. For the first trials, all of the previously listed water quality variables were included. However, a low number of observations of certain variables (i.e., N 10) in some segments necessitated their elimination before regression equations could be successfully derived.

Results of the first analyses are given in Table 10. Again, there is relatively little consistency from segment to segment or season to season among the major independent variables in the equations. It is not unexpected that SAV responses should differ from area to area because different SAV species are involved; also areal trends in water quality vary. In addition, the selection of variables can affect the outcome of the analysis.

As these analyses were, by necessity, limited by the 11-year SAV data base from the MD DNR and U.S. FWS, they are, at best, suggestive rather than predictive. With small data sets, it is unlikely that any independent variable beyond the first or second has predictive capability.[4]

Therefore, these results should be viewed with some caution, as they are preliminary at best. In addition to the above caveats, it is difficult to identify or eliminate spurious correlations, or those where a variable represents a surrogate or analog of the actual (but not tested) predictor. Also, in some segments, paucity of water quality leads to low degrees of freedom, weakening the statistical validity of the resulting equation.

Upper Bay--

In CB-1, 83 percent of SAV variability is explained by negative correlation with annual NO_3 concentrations, thus supporting the hypothesis stating that nutrient enrichment adversely impacts rooted vegetation. Addition of the dissolved oxygen variable, explains 84 percent of SAV variability. Summer means of chlorophyll a and dissolved oxygen explain 78 percent of SAV variability; these are positive correlations. Probably both SAV and phytoplankton are responding positively to the same factor(s), possibly summer inflow or another non-tested variable.

In CB-2, a less readily explained relationship exists: 92 percent of SAV variability is explained by correlation with annual NO_3 (negative), and turbidity. Using summer means only, 94 percent of variability is explained by total phosphorus and turbidity alone. While a strong negative correlation with NO_3 and total phosphorus, again, tends to support the nutrient and SAV hypothesis, the positive correlation with turbidity is puzzling (however, see previous discussion of linear regressions).

In CB-3, 85 percent of SAV variability can be explained by a positive correlation with annual total nitrogen and turbidity, a relationship not expected and not readily explained. Some complex process may be

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[4] Personal communication: "Interpreting Multiple Regression Analyses," R. Ulanowicz, Chesapeake Biological Laboratory, 1982.

TABLE 10. MULTIVARIATE REGRESSIONS OF SAV TO WATER QUALITY VARIABLES, ACROSS TIME BY SEGMENT

Segment	Time	Regression	r2	$p < F$
CB-1	Annual	1) SAV = 62.3 - 53.9 (NO_3)	.82	0.0016
		2) SAV = 12.0 - 68.0 (NO_3) + 6.0 (DO)	.89	0.004
	Annual/ lagged	SAV = 34.9 + 4.4 (DO)	.43	0.08
	Summer	SAV = - 87.1 + .67 (CHL) + 11.8 (DO)	.78	0.0237
CB-2	Annual	1) SAV = 4.8 + 2.7 (TN) - 65.6 (TP) + .8 (Turbid) - 1.8 (DO)	.99	0.0018
		2) SAV = 6.7 + 4.3 (NO_3) - 68.9 (TP) + 0.9 (TURBID) - 2.2 (DO)	.99	0.006
		3) SAV = 6.1 - 63.2 (TP) + 0.8 (TURBID) - 1.6 (DO)	.99	0.004
	Annual/ lagged	SAV = 36.5 - 3.2 (DO) - 0.37 (CHL)	.81	0.04
	Summer	1) SAV = - 15.7 + 1.0 (TURBID)	.87	0.0068
		2) SAV = - 12.2 - 32.4 (TP) + 1.0 (TURBID)	.94	.0148
CB-3	Summer	1) SAV = - 8.2 + 16.3 (TN)	.74	.0065
		2) SAV = - 18.1 + 19.1 (TN)	.85	.0088
	Spring/ lagged	2) SAV = 19.9 - 15.5 (NO_3)	.71	.0088
		SAV = 21.2 - 11.4 (NO_3) - 0.2 (CHL)		
CB-4	Spring/ lagged	SAV = - 1.4 + 9.0 (TP) + 0.02 (CHL) + 0.1 (TURBID)	.99	.0005
	Summer/ lagged	SAV = 8.4 - .5 (TN) - 6.5 (NO_3) - .3 (CHL)	.99	.0001
CB-5	Annual	1) SAV = - 29.8 + 4 (DO)	.71	.0173
		2) SAV = 6.7 - 13.2 (TN) + 2.5 (DO)	.85	.0224
		3) SAV = - 7.0 - 15.4 (TN) - 1.9 (SECCHI) + 3.2 (DO)	.94	.0244
		4) SAV = - 16.2 - 13.0 (TN) - 16.4 (NO_3) - 1.5 (SECCHI) + 4.4 (DO)	.98	.0322

(continued)

TABLE 10. (continued)

Segment	Time	Regression	r2	$p < F$
	Spring	SAV = 16.0 - 16.5 (TN) + (NO_3)	.92	.0065
EE-1	Annual	SAV = 43.7 - 49.3 (NO_3)	.48	0.13
	Annual/ lagged	SAV = 4.6 + 12.6 (TURBID) -245.25 (TP)	.93	0.02
EE-3	Spring	1) SAV = 1.6 + 0.48 (CHL)	.94	0.03
		2) SAV = 9.5 + 0.49 (CHL) - 13.9 (TN)	.99	0.02
		3) SAV = 11.5 + 0.48 (CHL) - 12.0 (TN) - 53.9 (TP)	.99	0.0001
	Spring/ lagged	SAV = - 1.98 + 0.38 (CHL)	.85	0.08
	Summer	SAV = 46.7 - 1.8 (TURBID) - 19.1 (TN)	.99	0.07
	Summer/ lagged	SAV = 26.9 - 1.5 (TURBID) - 156.4 (NO_3) + 0.68 (DO)	.99	0.001
ET-4	Annual	SAV = 82.2 + 40.7 (TP) -6.1 (DO)	.69	.0553
	Spring/ lagged	SAV = 93.4 - 63.4 (NO_3)	.98	.0014
	Summer/ lagged	SAV = 43.1 - 45.8 (NO_3) + 130.4 (TP) - 0.1 (CHL)	.99	.0339
ET-5	Summer/ lagged	SAV = - 5.3 + 10.1 (DO)	.68	.0447
WT-2	Annual	SAV = 64.6 - 4.7 (TURBID)	.92	.0025
	Summer	1) SAV = 50.2 - 2.1 (TURBID)	.92	.0406
		2) SAV = 12.5 + 19.3 (TN) - 1.4 (TURBID)	.99	.0254
	Summer/ lagged	SAV = 54.0 - 53.9 (NO_3)	.99	.0392
WT-3	Annual	SAV = 31.0 - 139.1 (NO_3)	.99	0.02
WT-5	Annual	1) SAV = 48.3 - 0.65 (CHL) - 13.6 (NO_3) - 6.9 (TN)	.96	0.056
		2) SAV = 38.3 - 0.69 (CHL) 14.8 (NO_3)	.88	0.04

(continued)

TABLE 10. (continued)

Segment	Time	Regression	r2	P≤F
	Annual/ lagged	1) SAV = - 9.13 + 40.97 (SECCHI) - 10.92 (TN)	.89	0.11
		2) SAV = - 32.6 + 46.2 (SECCHI)	.69	0.08
	Summer	SAV = 7.3 - 0.4 (CHL) + 14.5 (SECCHI)	.99	0.001
WT-6	Annual/ lagged	SAV = - 30.6 + 53.5 (SECCHI) + 6.6 (TN)	.99	0.04

operating, or the results may represent a spurious correlation or autocorrelation. Comparison with spring means of the previous year generates an equation with 84 percent of SAV variability explained by negative correlation with NO_3 and chlorophyll a. This latter relationship is more comparable to equations for CB-1 and CB-2.

No significant relationships were found between annual water-quality-variable means and SAV trends in CB-4. Comparison to seasonal means of the previous year produces two predictive equations: the spring variables of total phosphorus and turbidity (both positive) and the summer variables of nitrate and chlorophyll (both negative). In this segment, SAV may respond positively to nutrient availability in the spring, but negatively to the summer loadings.

In segment CB-5, 85 percent of SAV variability is explained by annual total nitrogen (negative) and dissolved oxygen (positive) concentrations. Comparison to spring means produces an equation which explains 92 percent of SAV variability by negative correlation with total nitrogen and a positive correlation with nitrate.

Eastern Shore--

In segment EE-1, Eastern Bay, no significant correlations were identified using current annual or seasonal means. Comparison of SAV trends with annual water quality variable means of the preceding year produces an equation which explains 93 percent of SAV variability by turbidity (positive) and total phosphorus (negative).

Segment EE-3, Honga River and Tangier Sound, had no correlations identified with annual means. Spring means of chlorophyll, both current and preceding year, explain a major proportion of SAV variability. In the summer, negative correlations with turbidity and total nitrogen produce an equation explaining 99 percent of SAV variation but significant only at the 93 percent level because of the low number of observations ($p \leq 0.07$). Water quality variables of the preceding summer entering into the predictive equation are turbidity and NO_3 (both negative), and dissolved oxygen (positive).

In segment ET-4 (Chester River), 69 percent of SAV variability is predicted by annual total phosphorus (positive) and dissolved oxygen (negative). Comparison with seasonal variables of the previous year shows a negative correlation with nitrate for both the spring and summer; however, relatively few observations were available to produce these equations.

In ET-5 (Choptank River), the only significant relationship results from a comparison of SAV to the summer variables of the previous year; 68 percent of SAV variability is explained by dissolved oxygen alone. This relationship is difficult to explain, although it may represent a response of SAV to some other factor for which dissolved oxygen is a surrogate.

Western Shore--

Ninety-two percent of SAV variability in WT-2, the Gunpowder River, can be explained by a negative correlation with the annual means of turbidity alone. Comparison with summer means of the current year produces a regression equation explaining 92 percent of SAV variability by a negative correlation with turbidity alone. Addition of total nitrogen and NO_3 increases goodness-of-fit to 99 percent. Comparison with the spring means of the preceding year produces an equation that explains 99 percent of the observed SAV variation by a correlation with total nitrogen and nitrate. Summer nitrate and total nitrogen concentrations of the preceding year explain 99 percent of SAV variability, as well. However, the small number of observations (n = 10) that were used to generate these equations is reason for very cautious interpretation.

In segment WT-3, the Middle River, the annual nitrate concentrations alone produce an equation explaining 99 percent of SAV variation. No other significant equations were produced.

In the Patapsco River, WT-5, the annual nitrate and chlorophyll concentrations account for 88 percent of the observed SAV variability. An addition of total nitrogen increases goodness-of-fit to 99 percent. All of the correlations are negative. Sixty-nine percent of SAV variation can be predicted by an annual means of Secchi depth the preceding year (for example, when Secchi depth increases, so does SAV). An addition of total nitrogen (negative) increases goodness-of-fit to 89 percent, but decreases significance to the ($P<0.10$) level. The Summer means of chlorophyll and Secchi depth can explain 99 percent of SAV variation. In this urbanized estuary, these equations all relate SAV success to decreases in nutrients and chlorophyll, and increases in Secchi depth.

In segment WT-6, the Magothy River, 99 percent of SAV variability can be explained by Secchi depth and total nitrogen of the preceding year.

Summary of Multivariate Regressions

In general, SAV responded negatively to nutrients, particularly TN and NO_3 concentrations. The multivariable equations are suggestive, but not conclusive. It should be emphasized that none of these relationships are intrinsically causative; SAV could be responding to a non-tested variable co-occurring with the tested predictors.

Comparison of Segments

The preceding linear and multiple regression analyses serve to identify water quality factors that may be affecting SAV abundance within each segment. To determine if any factor, or factors, could be acting consistently on all segments, a nonparametric test, Spearman's rank-correlation coefficient, was used. Total percent vegetation within each segment was compared with a number of water quality variables, including TN, NO_3, NH_3, TP, DO, and chlorophyll a. Annual means, five-year means, and maximums of various parameters were tested. The Maryland DNR and U.S. FWS SAV data from 22 Maryland Bay segments were used. Results are given in Table 11.

Percent SAV was compared for possible positive or inverse relationships with nutrients, chlorophyll a, and dissolved oxygen. Significant inverse relationships were identified between percent SAV and mean annual TN of both the current and preceding year ($p \leq 0.001$). In addition, if 5-year means of SAV are compared to 5-year means of TN, they are significant at the 95 percent level. There was no apparent relationship between SAV and annual NO_3, but a significant negative correlation was observed between SAV and NO_3 of the preceding year ($p \leq 0.025$). No significant correlations were found between SAV and total phosphate. When chlorophyll a levels (an indication of possible nutrient enrichment) are compared to submerged aquatic vegetation levels, a significant correlation occurs with maximum chlorophyll a of the preceding year. In addition, the relationship between SAV to mean annual chlorophyll a (of current year) is significant at the 90 percent level.

In general, on a comparative segment basis, SAV appears to respond negatively to increased total nitrogen of both the current and preceding year. This, as well as the negative relationship with NO_3 of the preceding year, seems to support the results of the previous regression analysis. The negative response to maximum chlorophyll a, an analog of both nutrient loading and turbidity, also supports the SAV and nutrient enrichment hypothesis.

TABLE 11. SPEARMAN-RANK CORRELATION COEFFICIENT RESULTS FOR SUBMERGED AQUATIC VEGETATION AGAINST WATER QUALITY VARIABLES. r_s = CORRELATION COEFFICIENT, ALPHA = LEVEL OF SIGNIFICANCE, n = 22

x	y	r_s	alpha
SAV	- $\bar{x}$ annual TN	0.70	0.001
% SAV	- $\bar{x}$ annual TN of preceding year	0.70	0.001
5 yr $\bar{x}$ % SAV	- 5 yr $\bar{x}$ TN	0.41	0.05
% SAV	- $\bar{x}$ annual NO_3	0.08	N.S.
% SAV	- $\bar{x}$ annual NO_3 of preceding year	0.43	0.025
% SAV	- $\bar{x}$ summer TN	0.11	N.S.
% SAV	- $\bar{x}$ maximum summer TN	-0.09	N.S.
5 yr $\bar{x}$% SAV	- 5 yr $\bar{x}$ summer TN	-0.11	N.S.
% SAV	+ $\bar{x}$ annual TP	0.10	N.S.
% SAV	- $\bar{x}$ annual TP	0.08	N.S.
% SAV	+ $\bar{x}$ annual TP of preceding year	0.03	N.S.
% SAV	+ maximum annual TP	0.08	N.S.
% SAV	+ maximum annual TP of preceding year	0.06	N.S.
% SAV	- $\bar{x}$ annual chl a	0.30	0.10
% SAV	+ $\bar{x}$ annual chl a	0.16	N.S.
% SAV	- $\bar{x}$ annual chl a of preceding year	0.19	N.S.
% SAV	+ $\bar{x}$ annual chl a of preceding year	0.13	N.S.
% SAV	- annual maximum chl a	0.37	0.05
% SAV	- annual max. chl a of preceding year	0.25	N.S.
% SAV	+ annual maximum chl a	0.20	N.S.
% SAV	+ annual dissolved oxygen	0.37	N.S.

SECTION 3
STATISTICAL ANALYSES OF BENTHIC ORGANISMS

SHANNON-WEAVER DIVERSITY INDEX AND OTHER TESTS

Main Bay

Use of the Shannon-Weaver diversity index

$$\bar{H} = \Sigma \left(\frac{n_i}{N}\right) ln \left(\frac{n_i}{N}\right)$$

to compare the bentic community with the contamination of bed sediments by metals (C_I, Contamination Index) showed no apparent relationships in the main Bay. Temporal and spatial variability in H appeared to be related more to estuarine salinity gradient and sediment type than to the C_I.

The ratio of annelids to molluscs and crustaceans has been cited as an indication of environmental stress. These ratios were compared to both the C_I and T_I using a nonparametric procedure, the Spearman Rank Correlation test. However, no significant relationship could be identified. One difficulty is that benthic samples for biological analysis did not come from the exact areas where toxic materials were sampled. Innate variability of organism distribution would tend to obscure relationships in such cases.

To avoid variability resulting from small scale differences, the annelid:mollusc ratios were compared from areas where the C_I was greater than 4 and from areas where it was less than 4, using the Mann-Whitney U test. These differences were significant at about the 94 percent level. Areas where the C_I was > 4 had, in general, annelid:mollusc ratios > 15 ($\bar{X} = 28$; $n = 6$). Areas where the C_I was < 4 had ratios, in general, < 15 ($\bar{X} = 6.5$; $n = 13$).

Patapsco River and Elizabeth River

The Patapsco River and Baltimore Harbor area was investigated by Pfitzenmeyer in 1975 and by Reinharz in 1981. This tributary has been subjected to significant anthropogenic impact and could be expected to show more effects on benthic communities than does the main Bay.

Within the Patapsco, diversity ($\bar{H}$) generally declines along the gradient of increasing contamination of metals and organic chemicals (Bieri et al. 1982b) (Figure 3, Table 12). Only stations near the mouth of the Patapsco retained diversity comparable to that at the reference stations in the Rhode River. A group of stations in the inner estuary (PO 1,3,4 and 5) shows low diversities ($\bar{H} = 0.246 - 0.590$) and high redundancy (dominance by one or a few species)(Table 13). They are dominated by polychaetes, particularly Scolecolepides viridis. Stations P_2 and P_9, also with low diversities ($H = 0.678$ to 0.838), are dominated by polychaetes and oligochaetes. Two groups of stations in the mid-estuary (P_8, 10, 11) and (P_6, 7, 13) have diversity values ranging from 1.173 to 1.615, and are dominated by polychaetes, with a few molluscs (chiefly Macoma balthica), as well as some crustaceans. Stations P_{12} and 14 ($\bar{H} = 2.175$ to 2.879) have fauna dominated by a wide variety of polychaetes, molluscs, and crustaceans, similar to the Rhode River reference areas ($\bar{H} = 2.286$ to

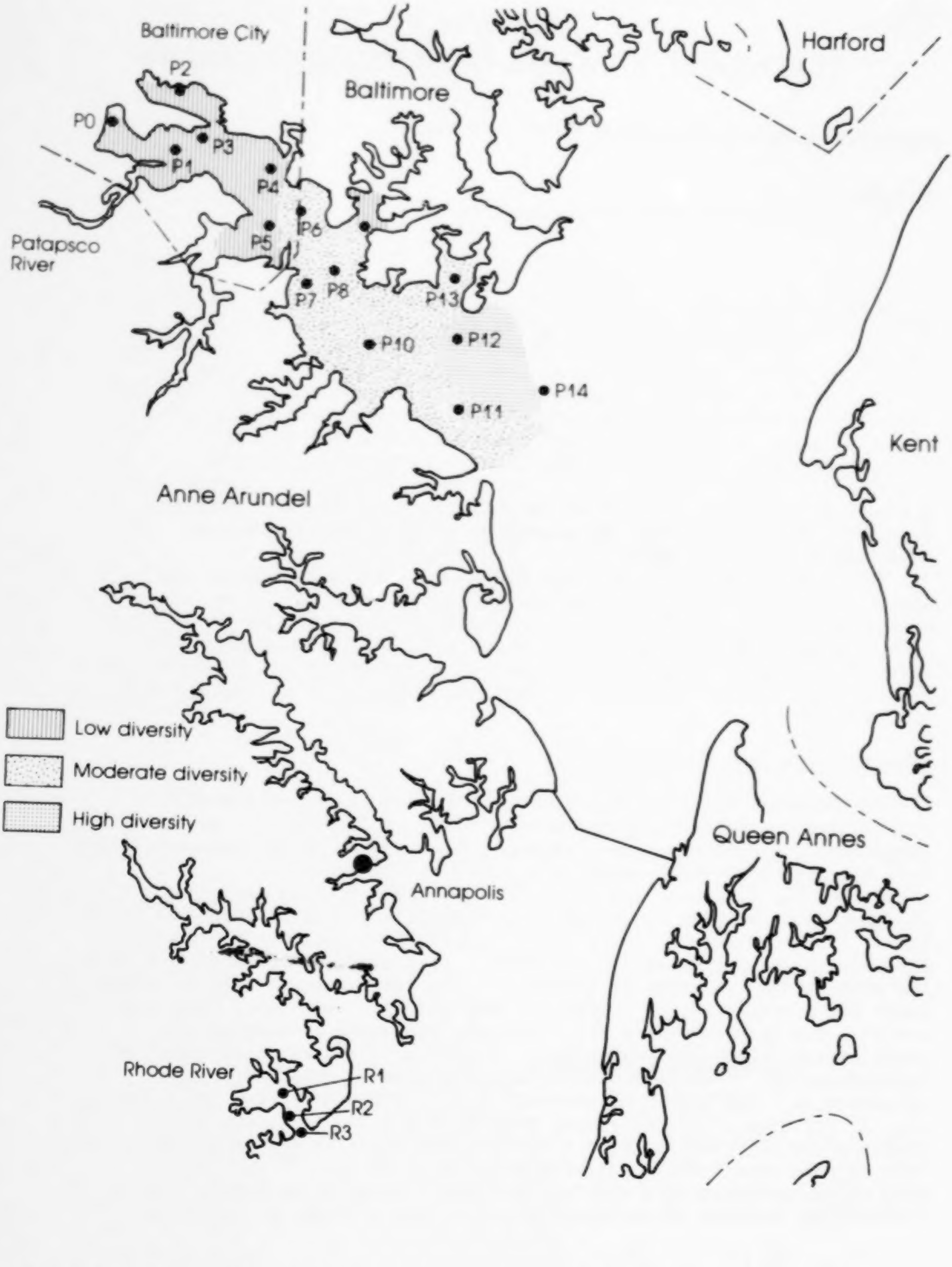
Baltimore City
Harford
Baltimore
P0
P1
P2
P3
P4
P5
P6
P7
P8
P10
P11
P12
P13
P14
Patapsco River
Kent
Anne Arundel
Low diversity
Moderate diversity
High diversity
Queen Annes
Annapolis
Rhode River
R1
R2
R3

Figure 3. Diversity index (d) of benthic communities in the Patapsco and Rhode Rivers (Reinharz 1981).

2.501). Comparison of groups by Student-Neuman-Keuls test shows that all groups are statistically different from one another. However, the same procedure using the Bonferroni (Dunn) test and Tukey's Studentized Range Test ranks groups 1 and 2 together, and 3 and 4 together.

TABLE 12. CONTAMINATION INDEX (C_I), TOXICITY INDEX (T_I), ANNELID:MOLLUSC AND ANNELID:CRUSTACEAN RATIOS FOR REINHARZ 1981 PATAPSCO RIVER STATIONS

Station	C_I*	T_I*	Annelid:Mollusc	Annelid:Crustacean
P0	55	26	23	-
1	20	13.8	15	-
2	131	-	-	-
3	164	100.4	51	253
4	58	8	11	1276
5	39	40.8	37	-
6	41	15.3	2	203
7	36	21	3	47
8	85	40.8	5	62
9	130	46	29	350
10	35	12.3	33	115
11	42	17	30	115
12	21	8.3	3	11
13	97	17	14	138
14	11	-	4	0.9

*X of at least two measurements, except for T_I at station P4

A comparison of reduced-diversity areas with both metal and organic contamination of sediment in the Patapsco estuary shows a strong visual correspondence (Figures 4 and 5). Reinharz (1981) found a virtual lack of salinity gradient in the estuary and (except for head branches of the Patapsco) consistent silt-clay sediment type. Thus, the significant differences in benthic diversity observed can best be explained by pollution, and by other anthropogenic influences (e.g., dredging). Species found in the most contaminated areas are opportunists, inhabiting only the upper layers of bed sediment. Arthropods and molluscs become more important in less-polluted regions of the estuary. For example, Leptocheirus plumulosus, a tube-dwelling amphipod, is an important member of the benthic community in the Rhode River reference area. In the Patapsco, Reinharz (1981) found this species in number only at P_{12} and P_{14}, the two least contaminated stations (Figure 6); elsewhere within the estuary, it was essentially absent. This is similar to the observation of Wolfe et al (1982), that the tube-dwelling amphipod Ampelisca was absent from the impacted areas of the New York Bight.

TABLE 13. DIVERSITY, REDUNDANCY, AND SPECIES NUMBER FOR PATAPSCO AND RHODE RIVER STATIONS. GROUPS ARE ALL SIGNIFICANTLY DIFFERENT FROM ONE ANOTHER.

Station	$\bar{H}$	r	N	station group
P_o	0.330	0.864	1	1
P_1	0.561	0.831	8	
P_3	0.343	0.906	8	
P_4	0.590	0.783	6	
P_5	0.246	0.893	4	
P_2	0.838	0.491	3	2
P_9	0.678	0.731	5	
P_8	1.173	0.630	8	3
P_{10}	1.296	0.634	10	
P_{11}	1.193	0.676	11	
P_6	1.615	0.523	9	4
P_7	1.416	0.603	10	
P_{13}	1.400	0.549	8	
P_{12}	2.879	0.307	16	5
P_{14}	2.715	0.312	14	
Reference				
R_1	2.286	0.420	15	6
R_2	2.348	0.369	13	
R_3	2.501	0.366	15	

P = Patapsco River stations,
R = Rhode River stations,
$\bar{H}$ = diversity,
r = redundancy,
N = number of species present.

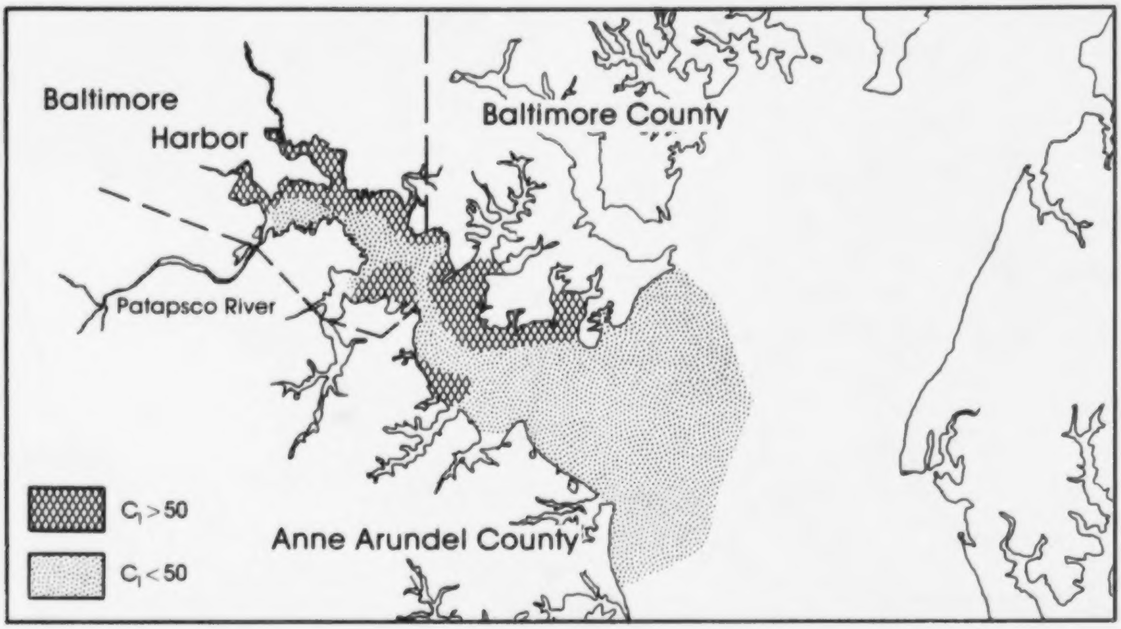
Baltimore Harbor
Baltimore County
Patapsco River
Anne Arundel County
$C_1 > 50$
$C_1 < 50$

Figure 4. Metal contamination of the Patapsco River (data from Biggs 1982).

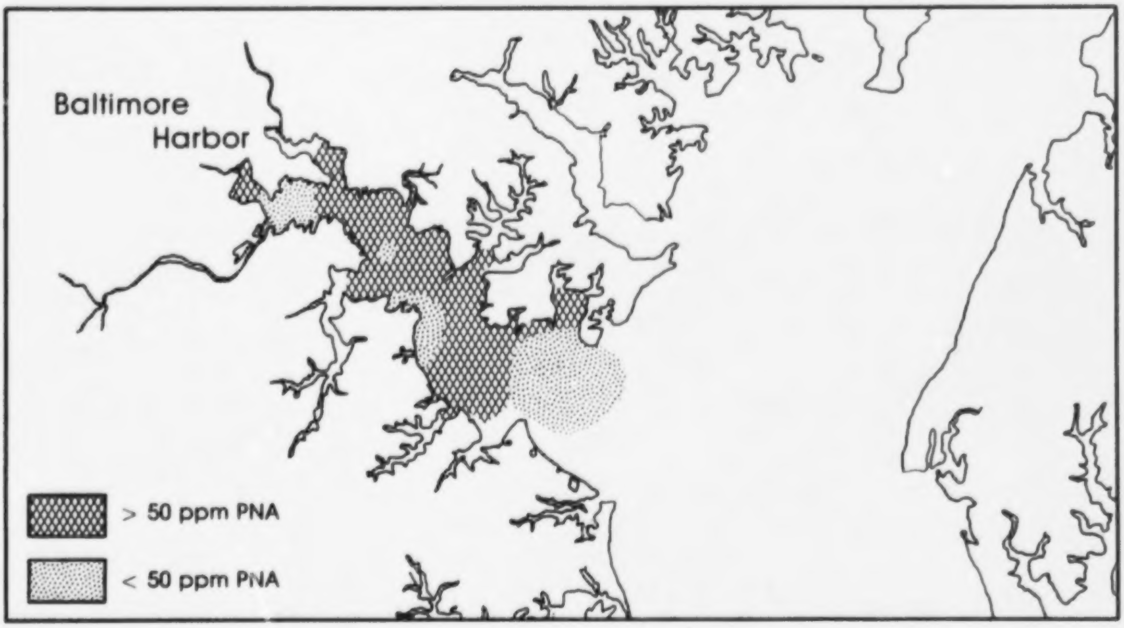
Baltimore Harbor
> 50 ppm PNA
< 50 ppm PNA

Figure 5. Distribution of PNA, Benzo(a)Pyrene in channel sediments from Baltimore Harbor and the Patapsco River (Data from Bieri et al. 1982).

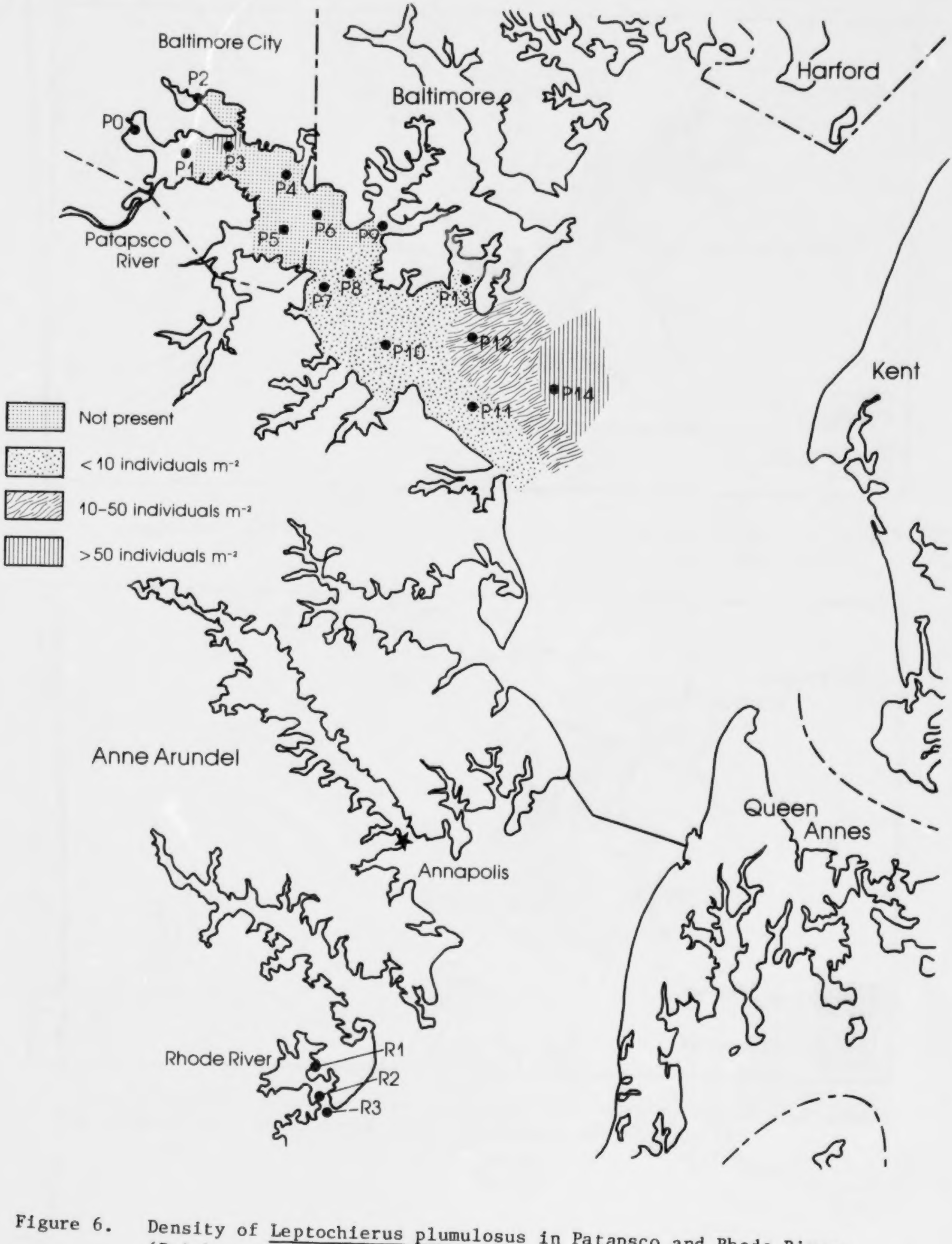
Baltimore City
Harford
Baltimore
P0
P1
P2
P3
P4
P5
P6
P7
P8
P9
P10
P11
P12
P13
P14
Patapsco River
Kent
Not present
< 10 individuals m⁻²
10–50 individuals m⁻²
>50 individuals m⁻²
Anne Arundel
Annapolis
Queen Annes
Rhode River
R1
R2
R3

Figure 6. Density of Leptochierus plumulosus in Patapsco and Rhode Rivers (Reinharz 1981).

Spearman rank correlation identified statistically significant relationships between contamination of bed sediments and various community attributes. Both the Contamination Index and the toxicity index were used. When these variables were compared to community diversity, the relationship between $\bar{H}$ and the T_I was significant at the 98 percent level. The Contamination Index did not compare as well to changes in diversity ($p \leq 0.08$), indicating that the weighted toxicity index measures potential biological impact better than the C_I alone.

Annelid:mollusc and annelid:crustacean ratios, based on numbers of individuals, were also compared to the C_I and T_I. (These ratios could not be calculated for all stations, as some had no crustaceans or molluscs). The relationship between the annelid:mollusc ratio and the C_I was not significant. However, using the T_I, the relationship was significant at the 95 percent level. In contrast, the annelid:crustacean ratio showed a significant relationship with the C_I ($p \leq 0.005$), but this ratio's relationship with the T_I was not significant. Only one T_I value could be calculated for station 4 (others were means of at least 3 values), and it appeared anomalously low. When this value was omitted from the calculation, the relationship became significant at the 92 percent level.

In the Elizabeth River, trends were less distinct, possibly because there were smaller differences in contamination from site to site within the river. However, Schaffner and Diaz (1982) identified a group of stations characterized by shallow dwelling, young populations of relatively low diversity; these stations were considered "impacted" by high levels of toxicants in the bed sediments.

The effect of sediment contamination on benthic organisms was further explored using bioassay techniques. Bioassays were performed on the sediments in the Elizabeth and Patapsco Rivers to determine the effect of sediments on survival rate of a burrowing amphipod (Rhepoxynius abronius) (Swartz and DeBen, in prep.). Statistical analysis indicated that survivorship strongly correlates with the degree of contamination (C_I) as well as the C_f for Ni and Zn, and approximates an exponential response to dose (Figure 7). An estimated LC_{50} would be $C_I = 15$. However, it should be emphasized that this association does not necessarily imply causation. Unmeasured metals or organic materials co-associated with the measured parameters may be contributing to, or actually causing, the observed mortality.

This view is supported by the observation that Spearman rank correlation of the annelid:mollusc and annelid:crustacean ratios with the contamination factor (C_f) for both Zn and Ni in the Patapsco showed no significant relationship. Thus, the relation between C_I and percent survival cannot be used to identify specific anthropogenic substances whose control can result in improved survival. However, it does indicate the probable presence of one or more toxic materials in the tested sediments.

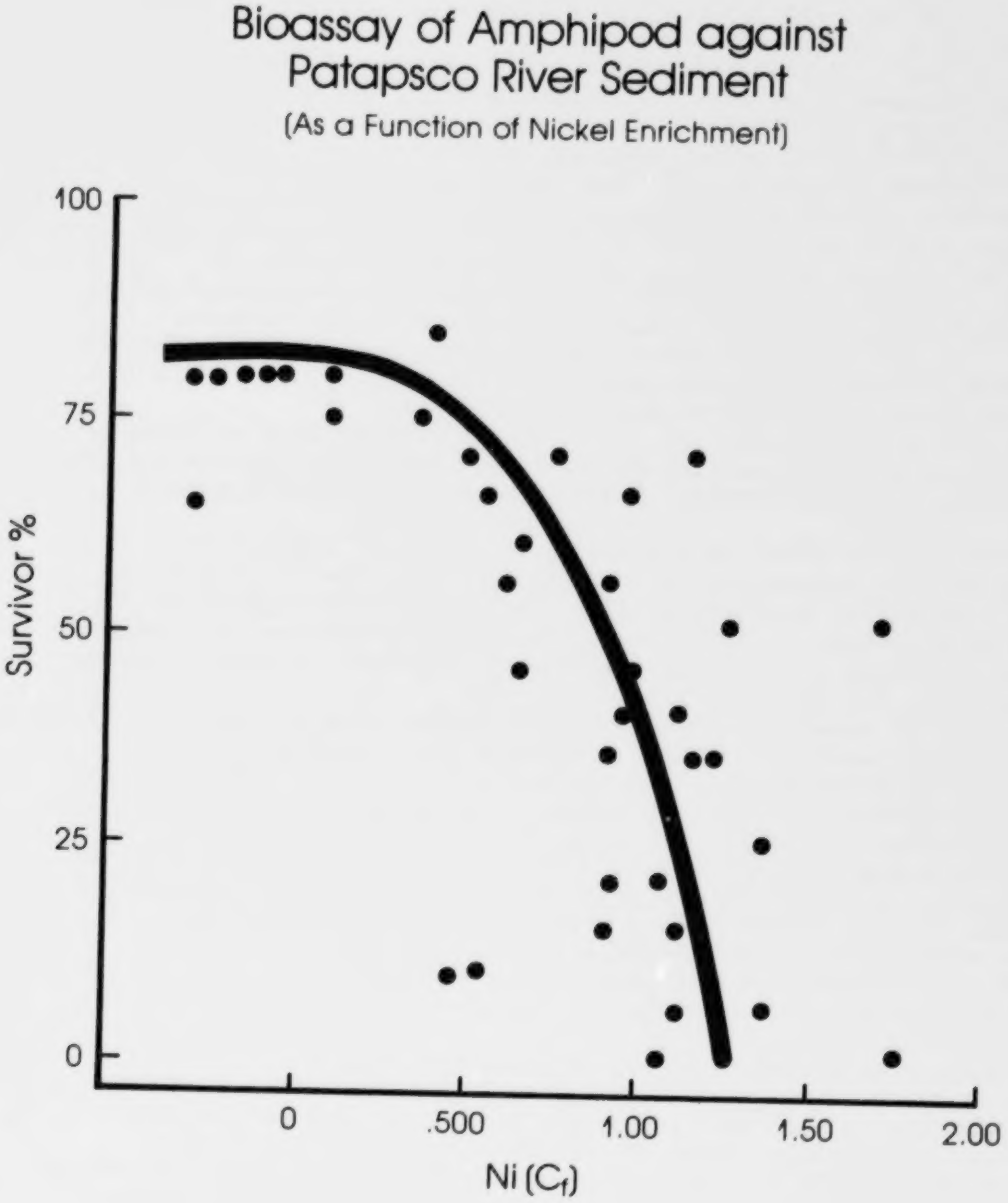

Figure 7. Bioassay of an amphipod against Patapsco River sediment (as a function of nickel enrichment).

SECTION 4
STATISTICAL ANALYSES OF FINFISH

JUVENILE INDEX

We used young juvenile finfish collected in four representative tributary areas of the Bay (Head of Bay, Potomac River, Choptank River, and Nanticoke River) to assess the impact of various environmental variables on finfish. The juvenile index is a better indicator of the abundance of fish stocks than landings because it is influenced less by fishing pressure and other factors. Though not immune to uncertainty as an index of stock abundance (Polgar 1982), the juvenile index was correlated with environmental variables to elucidate possible factors that affect the recruitment of young fish into the harvestable population.

It should be noted that the age determined in the MD DNR juvenile index includes young-of-the-year or age 0 for alewife, bluefish, shad, striped bass, white perch, and yellow perch. Year classes may be mixed for anchovy, catfish, menhaden, mummichog, silversides, spot, and weakfish.

Linear Regression Analysis

Using linear regression analysis, the juvenile index was compared with freshwater inflow and air temperature in the four tributaries. Results are summarized in Table 14a. In general, species responded positively to increases in flow and air temperature. In the Northern Bay, alewife responded negatively to February and March flows, which may be related to water temperature. The same may be true for anchovy and silversides. In both the Potomac and the Nanticoke, striped bass responded negatively to increased April air temperatures.

Although Table 14b indicates some subtle differences among species and among rivers basins as they relate to flow, the most believable results are those represented by the combined basins (aggregated flows and aggregated juvenile indexes). This approach shows that striped bass responds positively to strong spring flows results, which agrees with Mihurskey et al. (1981). The marine spawners, bluefish, menhaden, and spot are responding positively to strong fall, winter (which are combined as "late"), late, and annual flows. This argues for the estuarine transport of the larval and juvenile forms of these species by the upstream migration of the bottom waters (Tyler and Seliger 1978).

Multiple Regression Analysis

Analytical methodology--

A multivariate regression analysis was used to identify the freshwater variables that best explain the observed trends in the juvenile index. Flow relationships were characterized in terms of the maximum and minimum values of the freshwater flow to the head of the estuary determined as moving averages per month (7, 14, 21, 28 days). Temperature was calculated as the average monthly value using reference air temperatures from National Airport for the Potomac and Nanticoke Rivers and Baltimore City values for the upper Bay and the Choptank River, respectively.

TABLE 14a. RESULT OF LINEAR REGRESSION ANALYSIS OF JUVENILE INDEX AGAINST AIR TEMPERATURE

Species	Basin	Time	Corr. Coeff.	P ≤ 0.05
Alewife	Choptank	Feb. & March	-0.46	0.0281
Spot	Choptank	Feb. & March	0.43	0.0381
Spot	Choptank	Feb., March, April	0.44	0.0351
Atl. Menhaden	Potomac	Feb. & March	0.49	0.0165
Bluefish	Potomac	Feb. & March	0.66	0.0007
Catfish	Potomac	Feb. & March	0.45	0.0312
Spot	Potomac	Feb. & March	0.48	0.0209
Atl. Menhaden	Potomac	Feb. March, April	0.58	0.0037
Bluefish	Potomac	Feb. March, April	0.73	0.0001
Catfish	Potomac	Feb. March, April	0.52	0.0109
Spot	Potomac	Feb. March, April	0.49	0.0170
Atl. Menhaden	Potomac	March	0.54	0.0078
Bluefish	Potomac	March	0.56	0.0051
Spot	Potomac	March	0.48	0.0210
Str. Bass Age 0	Potomac	April	-0.49	0.0178
Atl. Menhaden	Upper Bay	March	0.51	0.0136
Yel. Perch Age 0	Upper Bay	March	0.46	0.0286
Weakfish	Upper Bay	April	-0.42	0.0447
Mummichog	Choptank	February	-0.48	0.0216
Yel. Perch Age 0	Nanticoke	February	-0.52	0.0101
Spot	Nanticoke	March	0.42	0.0475
Str. Bass Age 0	Nanticoke	April	-0.44	0.0360
Spot	Choptank	Spring	0.52	0.0103

TABLE 14b. RELATIONSHIP AS REPRESENTED BY R V ALUES AND DETERMINED BY CORRELATION ANALYSIS (P ≤ 0.05) FOR FINFISH JUVENILE INDEX VERSUS FLOW (N = 24)

Species	Annual Flow	Winter Flow	Spring Flow	Summer Flow	Fall Flow	Early Flow	Late Flow
Choptank River							
Alewife				0.40			
W. Perch		-0.42					
Menhaden	0.48	0.50				0.56	
Mummichog		0.51				0.46	
Nanticoke River							
Anchovy	-0.49	-0.44	-0.43			-0.49	
Potomac River							
Striped Bass			0.38				
Bluefish		0.43					
Silversides	-0.46	-0.53				-0.46	
Upper Bay							
Spot					0.59		0.60
Striped Bass			0.47				
Bluefish		0.51					
Silversides	-0.54	-0.49	-0.41			-0.53	-0.42
Combined Basins							
Striped Bass			0.45				
Bluefish	0.42	0.52			0.43		0.52
Menhaden		0.60			0.46		0.41
Spot	0.45	0.42			0.67		0.65
Silversides	-0.60	-0.49			-0.43	-0.54	-0.51

Juvenile index data used in this analysis covered the period of 1958 to 1981 for Atlantic menhaden, spot, bluefish, Bay anchovy, striped bass, white perch, yellow perch, catfish, mummichog, alewife, and Atlantic silversides. Emphasis in the analysis is placed on freshwater spawners and selected forage fish because these species spawn within the Bay system, including the fluvial streams; they are hypothesized to have sensitive young life stages when exposed to higher concentrations of natural and anthropogenic factors than marine spawners.

The climatic data were obtained from Washington National Airport on the Potomac and from Baltimore-Washington International Airport for the upper reaches of the Bay. Flow was from the Environmental Protection Agency's STORET data bases at the NCC for each of the four basins at the fall line. Flow data were corrected to include the basin of half the CBP RET segments as well as the TF segments.

Water quality data for the analysis were computed from the CBP nutrient data sets and included TF-2, RET-2, CB-1, CB-2, EE-2, ET-5, ET-6, and ET-7. For each year, monthly geometric means were computed for use in the regression models. It must be noted that for the water quality data there is not a continuous record of data available.

In lieu of a non-continuous record of the water quality data, the initial analyses included only the juvenile indices, air temperature (surrogate of water temperature), and stream flow. For all months, the juvenile indices were regressed in a step-wise fashion using a maximum R^2 improvement against streamflow, and air temperature. This technique was developed by J.H. Goodnight of the SAS Institute and is considered to be superior to the step-wise procedures and almost as good as all possible regressions. This max R^2 method proceeds by finding the one variable model with the highest R^2, then the two variable model is found by adding the variable that would maximize the R^2 for the regression. Once the model is obtained, Max R^2 compares all possible switches of variables to see if another would further increase the R^2 until no further improvement can be made.

The selection of models is documented in maximum R^2 flow sheets for each basin showing the order of variables coming into the model, variable substitutions, and the associated R^2 for the one through n^{th} model. It may be noted that the maximum number of variables for each basin and species was not constant. For this work, the number of variables was limited by seven. Fewer number of variables in the model indicated the failure of the model and/or its components to meet an alpha probability level of less than 0.10.

Predictive regression models for each juvenile index species in each basin were obtained from the results of maximum r-squared regressions. Models were selected based on explainability of the variables to the juvenile indices and the change of the r-square values. Through the use of these models, regressions were performed, and equations were derived from which predictions can be made using the air temperature and stream flow. The derivation of these models was iterative until the optimally explainable model was found. Once the predictive models were derived, residuals and predictions were obtained. The predictive data were plotted against the raw juvenile index data using SAS Graph for comparisons. For each model, the R square, F value, and probability, as well as individual variable probabilities were tabulated.

Through the use of the residuals from each statistically significant equation, the water quality variables were tested. Because of the infrequent data in the Choptank and Nanticoke Rivers, the water quality tests in these rivers was excluded. Monthly Max R^2 step-wise regression of water quality variables including salinity, total nitrogen, total phosphorus, dissolved oxygen, and chlorophyll was performed against the residuals from the physical models to see if improvement can be made on the models. Because of the infrequent number of years available, we feel that these results may be considered suggestive only.

Striped Bass (*Morone saxatilis*)

Mihursky et al. (1981) showed that the highest five-day flow in April and the minimum December temperature explained about 80 percent of the variance associated with the success of the striped bass juvenile index (Figure 8) in the Potomac River. The present analysis confirms that freshwater flow and temperature are important variables that explain the variability associated with the success of the striped bass juvenile index in the Potomac. However, the analysis required five (5) variables (combinations of flow and temperature) to achieve an R^2 of 0.81 (Table 15)(Figure 9). Additional years are included in the CBP analysis, probably accounting for the small difference between the results of Mihursky et al. (1981) and this study. The importance of the minimum 21-day flow in May (My-MN Q21) may be simply a partial reciprocal of the maximum 28-day flow of May, or the minimum 21-day flow may be important in its own right.

A possible explanation for these relationships has been given by Mihursky et al. (1981) including the role of increased freshwater flow in April expanding the spawning range for egg and young larvae development and the role of low December temperatures in tying up organic detritus, which can later serve as a food substrate for microheterotroph growth. The latter is presumably food for copepods, which serve as an important food for larval striped bass (Heinle et al. 1976). The minimum 21-day flow in May may be a correlate of the high flow for this month.

The same variables were used in the analysis of flow and temperature relationships for the upper Bay, and Choptank and Nanticoke Rivers. The R-squared values were significant (Table 15) for the upper Bay, Choptank and Nanticoke Rivers, but were only 0.50, 0.56, and 0.34, respectively. The result of the predictive equations are shown in Figures 10, 11, and 12. In the upper Bay, the April minimum 7-day flow and May minimum 7- and 14-day flows appeared in the regression equation without a maximum flow being represented. This difference is speculated to result from the high tidal currents naturally associated with the Elk River and Chesapeake and Delaware Canal, the primary site of spawning in the upper Bay. High currents presumably maintain the neutrally buoyant eggs suspended in the water column (Mansueti 1958). The lack of a positive relationship between the juvenile index abundance and maximum April flows in the upper Bay is possibly the result of the transport of eggs and larvae toward the Delaware Bay during periods of high flow from the Susquehanna. The lack of temperature relationships in the upper Bay regressions is not clear, and only temperature relationships were expressed in the predictive equations for the Potomac and Nanticoke Rivers. Minimum flow relationships explain 56 percent of the variance in the Choptank, which is similar to the case for the upper Bay except the coefficients are different by several orders of magnitude.

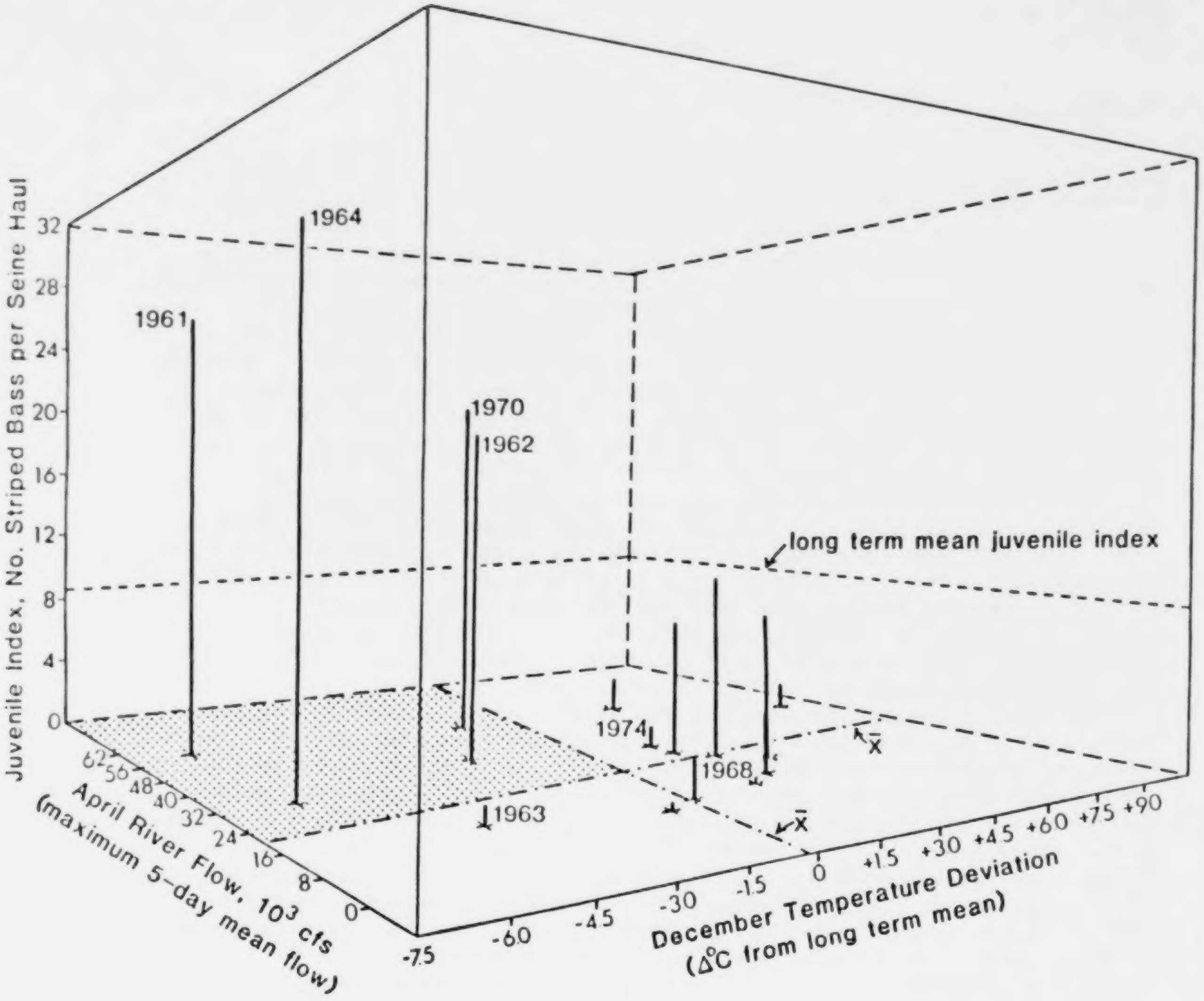

Figure 8. Three-dimensional plot of December temperature deviation from long-term average temperatures (± °C), Potomac River flow in April (cfs), and the juvenile striped bass abundance index. (From Mihursky et al. 1981).

TABLE 15. POTENTIAL PREDICTION EQUATIONS FOR STRIPED BASS JUVENILE INDICES AS DESCRIBED BY MULTIPLE REGRESSION

	Individual		Multiple			
	T	P /T/	F	P F	R-square	DF
POTOMAC RIVER						
Striped Bass = 56.65249						
+ (0.00062 x MY - MXQ28)	4.79	0.0002	13.73	0.0001	0.3110	21
+ (-0.00057 x MY - MNQ21)	-2.26	0.0379				
+ (-1.14294 x OC - ATMP)	-4.56	0.0003				
+ (1.13943 x AP - ATMP)	-3.18	0.0058				
+ (1.01890 x NV - ATMP)	2.82	0.0124				
UPPER CHESAPEAKE BAY						
Striped Bass = -4.32031						
+ (0.00027 x AP - MNQ7)	3.44	0.00026	6.80	0.0024	0.5050	22
+ (0.00133 x MY - MNQ7)	3.31	0.00035				
+ (-0.00096 x MY - MNQ14)	-2.73	0.0130				
CHOPTANK RIVER						
Striped Bass = -4.19136						
+ (0.10966 x AP - MNQ7)	4.52	0.002	13.19	0.0002	0.5568	22
+ (-0.071338 X AP - MNQ14)	-3.47	0.023				
NANTICOKE RIVER						
Striped Bass = 103.6655						
+ (-1.14745 x AP - ATMP)	-2.35	0.0291	5.15	0.0157	0.3399	22

Months:

NV = November
AP = April
JL = July
DC = December
MY = May
AG = August
MR = March
JN = June
SP = September

MX = maximium
MN = minimum
Q = flow
DO = dissolved oxygen
SALIN = salinity
ATMP = air temperature
CHL = chlorophyll *a*
TP = total phosphorus
TN = total nitrogen
7, 14, 21, 28 = moving average of days for freshwater flow

STRIPED BASS JUVENILE INDICES

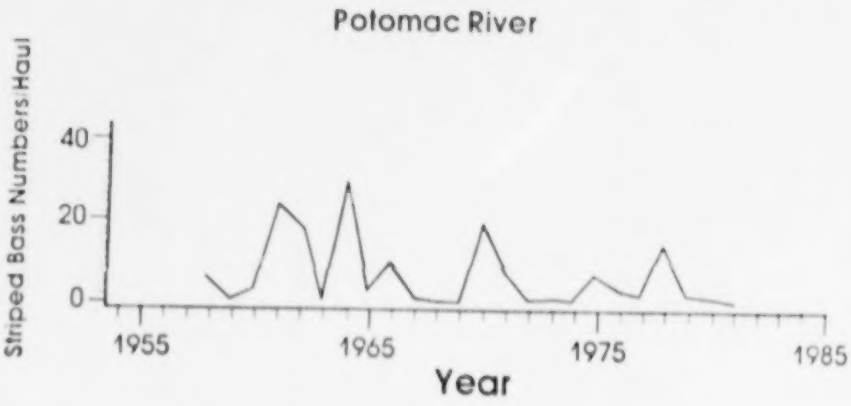

Figure 9. Juvenile indices for striped bass in the Potomac River.

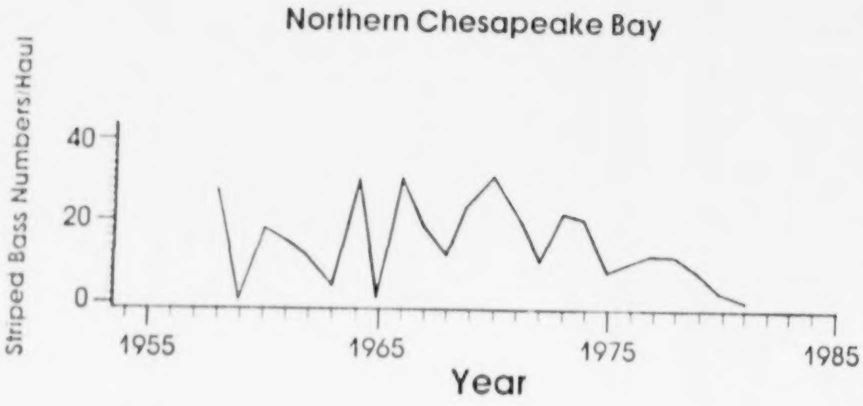

Figure 10. Juvenile indices for striped bass in the upper Bay.

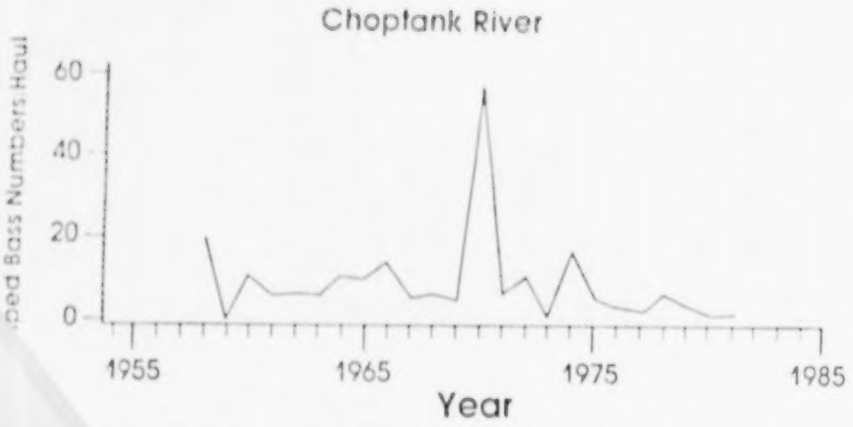

Figure 11. Juvenile indices for striped bass in the

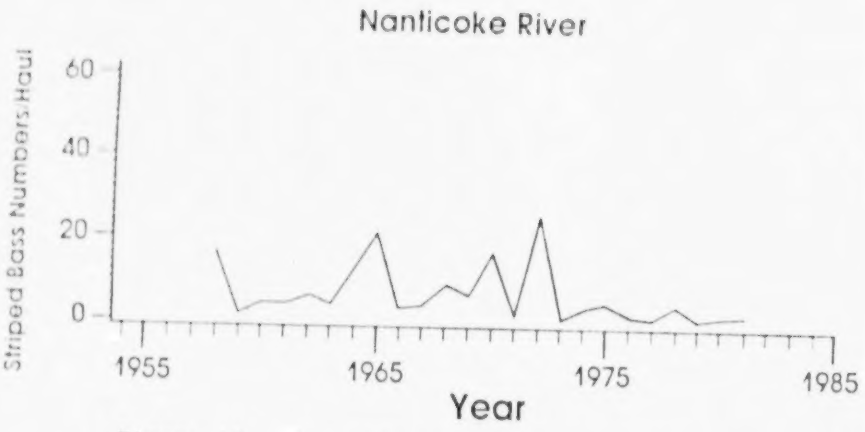

Figure 12. Juvenile indices for striped bass in the

A comparison of flow and temperature relationships among the four basins suggest that climatic variables explain a substantial amount of the variability associated with the striped bass juvenile index. However, there is little correspondence in specific variables appearing in the predictive equations for all four basins. This may reflect a true difference in the response of the juvenile striped bass to real differences in the physical features of these systems. Other possibilities exist such as masking of the response to physical variables through human intervention or quite simply an inability to sort out the "signal from the noise." Further work is required to increase our understanding of these relationships.

White Perch (Morone americana)

Flow and temperature relationships showed R-square values of 0.57 and 0.64 for the Choptank and Nanticoke Rivers, respectively. Values for the Potomac and Upper Bay were less than 0.50 (Table 16). In the Choptank, a positive maximum May 28-day flow and a negative December and April air temperature relationship were observed and, interestingly enough, similar variables occurred in the Potomac for striped bass, a closely related species. No clear explanation is available for the minimum April 21-day flow in the Choptank. These results are shown graphically in Figures 13 and 14.

The flow and temperature relationships for the Nanticoke are inconsistant in that several maximum flow variables exhibit negative coefficients (Table 16). No temperature relationships appeared with the flow variables.

Though significant (p _ 0.05), the R-squares for the model describing flow and temperature relationships for the Potomac and upper Bay were 0.48 and 0.46, respectively. This suggests that climatic factors may be less important for white perch juveniles in these two systems than in the Choptank and Nanticoke.

Ambient Water Quality Variables and Juvenile Index

We hypothesized that water quality variables may explain an important component of the variability associated with the juvenile indices. This is based on the knowledge that the tolerance of a given species may be exceeded, e.g., dissolved oxygen, salinity, and temperature, or there may be an indirect relationship expressed through the food web, e.g., nutrients and chlorophyll a. We did not test for toxic chemicals because the temporal spatial coverage of these materials is too low to define meaningful relationships. These materials are discussed elsewhere in this report (Chapters 2 and 3, Appendix B).

The approach used was to regress ambient water quality variables against the residuals associated with the multiple regression equations that predicted the success of the juvenile index based on freshwater flow and temperature. The SAS procedure was followed. The approach chosen was based on the relatively low number of annual observations, often less than 10, which could be related to the climatic variables (N approximated 21 to 24 annual observations).

TABLE 16. POTENTIAL PREDICTION EQUATIONS FOR WHITE PERCH JUVENILE INDICES AS DESCRIBED BY MULTIPLE REGRESSION

	Individual		Multiple			
	T	P /T/	F	P F	R-square	DF
POTOMAC RIVER						
White Perch = 54.12456						
+ (0.00059 x MY - MXQ7)	3.67	0.0016	5.77	0.0056	0.4767	22
+ (-0.00130 x JN - MNQ28)	-1.62	0.1210				
+ (-1.40576 x JA - ATMP)	-1.68	0.1084				
UPPER CHESAPEAKE BAY						
White Perch = -193.11905						
+ (0.000010 x AP - MXQ28)	1.16	0.2640	2.93	0.0436	0.4629	22
+ (3.03348 x MY - ATMP)	2.62	0.0179				
+ (-0.00026 x AP - MNQ21)	-1.60	0.1274				
+ (-0.00069 x MY - MNQ21)	-2.08	0.0527				
+ (0.00151 x MY - MNQ7)	3.08	0.0068				
CHOPTANK RIVER						
White Perch = 197.73527						
+ (0.01513 x MY - MXQ28)	2.09	0.0521	5.69	0.0043	0.5723	12
+ (-1.10864 X DC - ATMP)	-2.24	0.0386				
+ (-2.48733 X AP - ATMP)	-3.25	0.0047				
+ (-0.04094 X AP - MNQ21)	-3.90	0.0011				
NANTICOKE RIVER						
White Perch = -3.54591						
+ (0.08212 x JN - MNQ21)	2.93	0.0090	6.43	0.0014	0.6411	22
+ (-0.02935 x JN - MXQ7)	-2.31	0.0330				
+ (-0.04837 x MY - MXQ28)	-4.17	0.0006				
+ (-0.13289 x MY - MXQ14)	5.33	0.0001				
+ (-0.07899 x MY - MXQ7)	-4.64	0.0002				

Months:
NV = November
AP = April
JL = July
DC = December
MY = May
AG = August
MR = March
JN = June
SP = September

MX = maximium
MN = minimum
Q = flow
DO = dissolved oxygen
SALIN = salinity
ATMP = air temperature
CHL = chlorophyll a
TP = total phosphorus
TN = total nitrogen
7, 14, 21, 28 = moving average of days for freshwater flow

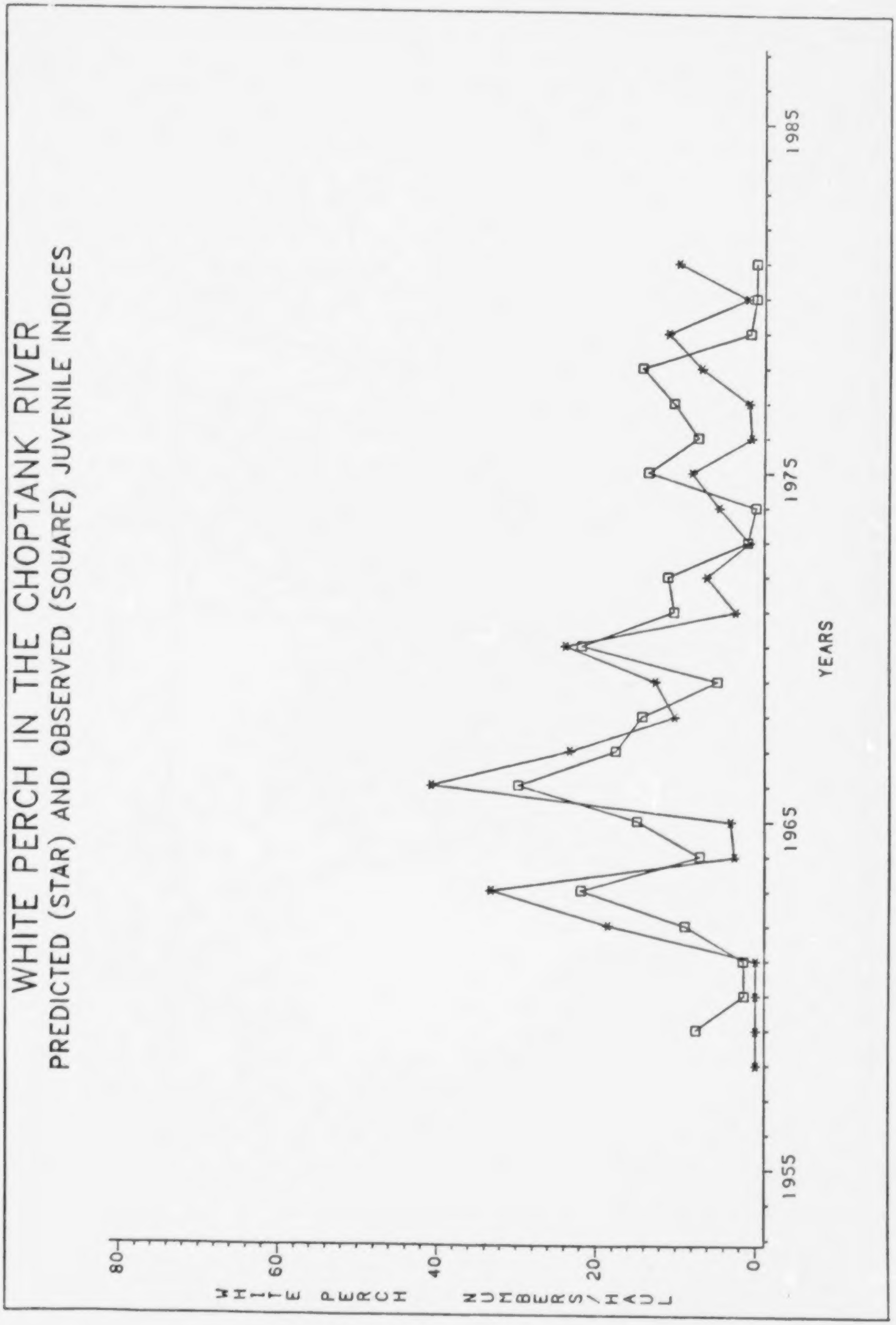

Figure 13. Juvenile indices for white perch in the Choptank River.

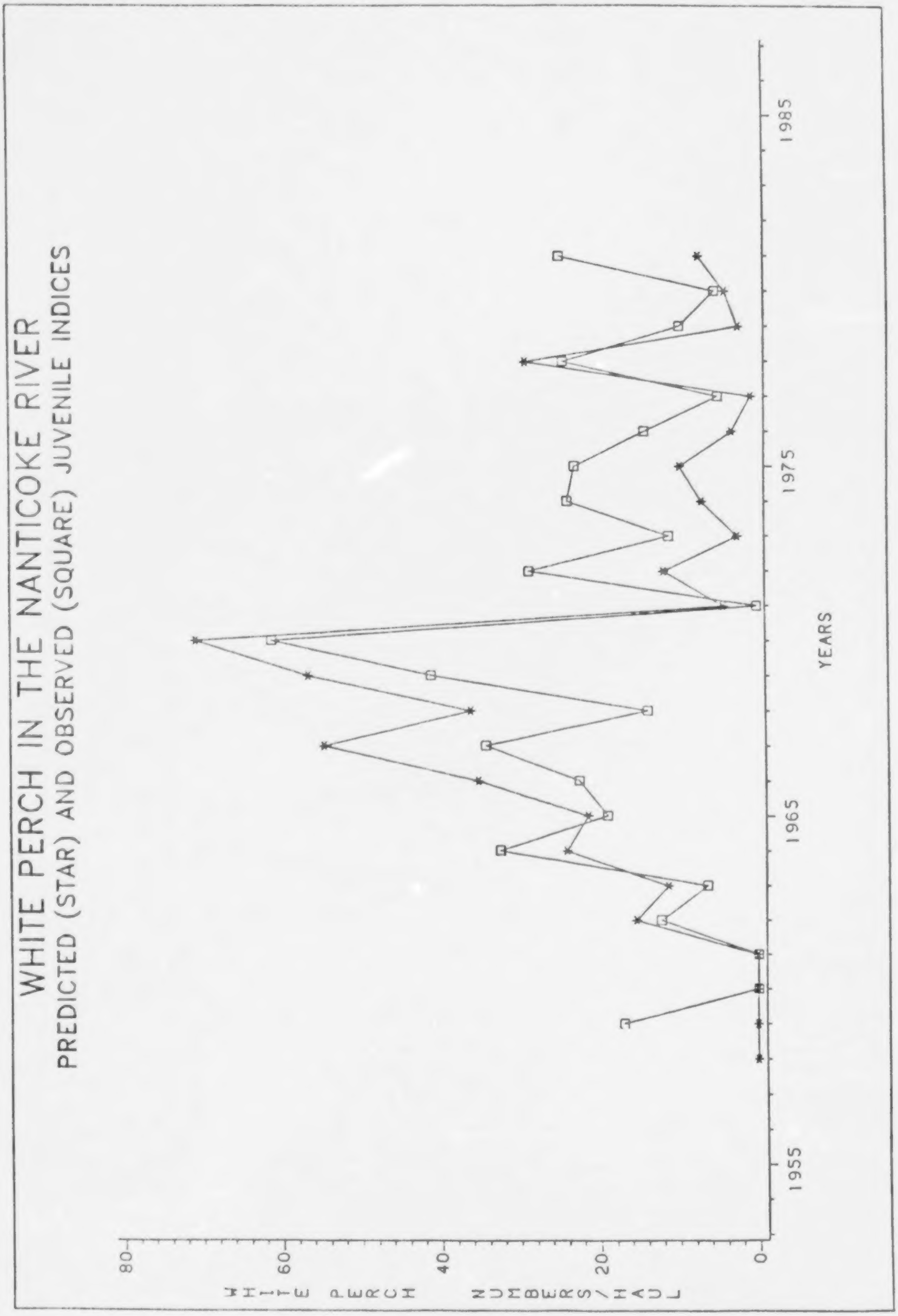

Figure 14. Juvenile indices for white perch in the Nanticoke River.

Striped Bass

The statistically significant relationships (p 0.05) are shown in Table 17. Only the Nanticoke River lacked any significant relationships. Dissolved oxygen explained 81 percent of the variability associated with the climatic residuals in the upper Bay and the Potomac for September and June, respectively. Total nitrogen appeared in the residual relationship for the Potomac and Choptank Rivers, respectively. Chlorophyll a and salinity co-occurred in the upper Bay.

It is difficult to ascribe cause and effect relationships to the present analyses. We view the approach more as a screening tool to provide guidance for further study. The linkage between dissolved oxygen and nutrients was made in Chapter 1. The limited field observations for dissolved oxygen in the reach of the estuaries where the larval and juvenile striped bass occur limit our ability to define a limiting condition for survival.

White Perch

Seven predictive models were developed to show regressing water quality variables against climatic residuals for the Potomac (Table 18). Salinity appeared in three models that may be an auto-correlate with freshwater flow. Phosphorus occurred in four, and nitrogen occurred in two models. The monthly significance of these relationships is not clear. Many of the R-square values are 0.50 or greater making them interesting candidates for further study.

In the upper Bay, the March total nitrogen explained 83 percent of the variability. The tidal freshwater and brackish reaches of the upper Bay are generally believed to be phosphorus limited, more so than nitrogen in terms of phytoplankton biomass yield. Thus, the high R-square for nitrogen is difficult to explain and may be a surrogate for some other factor or simply a chance occurrence.

TABLE 17. AMBIENT WATER QUALITY VARIABLES* THAT SIGNIFICANTLY IMPROVE THE LINEARITY OF THE RESIDUALS FROM THE POTOMAC RIVER PREDICTION EQUATIONS FOR STRIPED BASS JUVENILE INDICES

	Variables	F	R - Square	DF	P F
POTOMAC RIVER					
Model one	JN - DO	9.05	0.5307	9	0.0169
Model two	JL - TN	5.14	0.3635	10	0.0496
UPPER CHESAPEAKE BAY					
Model two	JL-CHL, JL-SALIN	7.10	0.6698	9	0.0207
Model three	SP - DO	21.56	0.8118	6	0.0056
CHOPTANK RIVER					
Model one	AG - TN	7.81	0.6612	5	0.0491

*Note these variables are not continuous over the period of record for juvenile indices and, for this reason, these water quality variables in the models must be considered suggestive only.

Months:
NV = November
AP = April
JL = July
DC = December
MY = May
AG = August
MR = March
JN = June
SP = September

MX = maximium
MN = minimum
Q = flow
DO = dissolved oxygen
SALIN = salinity
ATMP = air temperature
CHL = chlorophyll *a*
TP = total phosphorus
TN = total nitrogen
7, 14, 21, 28 = moving average of days for freshwater flow

TABLE 18. AMBIENT WATER QUALITY VARIABLES* THAT SIGNIFICANTLY IMPROVE THE LINEARITY OF THE RESIDUALS FROM THE POTOMAC RIVER PREDICTION EQUATIONS FOR WHITE PERCH JUVENILE INDICES

	Variables	F	R - Square	DF	P F
POTOMAC RIVER					
Model one	MR - TN	6.67	0.5263	7	0.0417
Model two	AP-SALIN	8.83	0.5577	8	0.0208
Model three	MY - TP MY-SALIN	5.10	0.5930	9	0.0430
Model four	JN - TP	8.37	0.5114	9	0.0201
Model five	JN - TP JN-SALIN	15.63	0.8171	9	0.0026
Model six	JL - DO JL - TP	4.69	0.5395	10	0.0450
Model seven	DC - TN	15.31	0.7185	7	0.0079
UPPER CHESAPEAKE BAY					
Model one	MR - TN	30.47	0.8839	5	0.0053
Model two	SP-SALIN	10.18	0.6706	6	0.0245
CHOPTANK RIVER					
No significant Model found (limited # available WQ years)					

*Note these variables are not continuous over the period of record for juvenile indices and, for this reason, these water quality variables in the models must be considered suggestive only.

Months:
NV = November
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MX = maximium
MN = minimum
Q = flow
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SALIN = salinity
ATMP = air temperature
CHL = chlorophyll a
TP = total phosphorus
TN = total nitrogen
7, 14, 21, 28 = moving average of days for freshwater flow

SECTION 5
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